ERDC/EL TR-12-26

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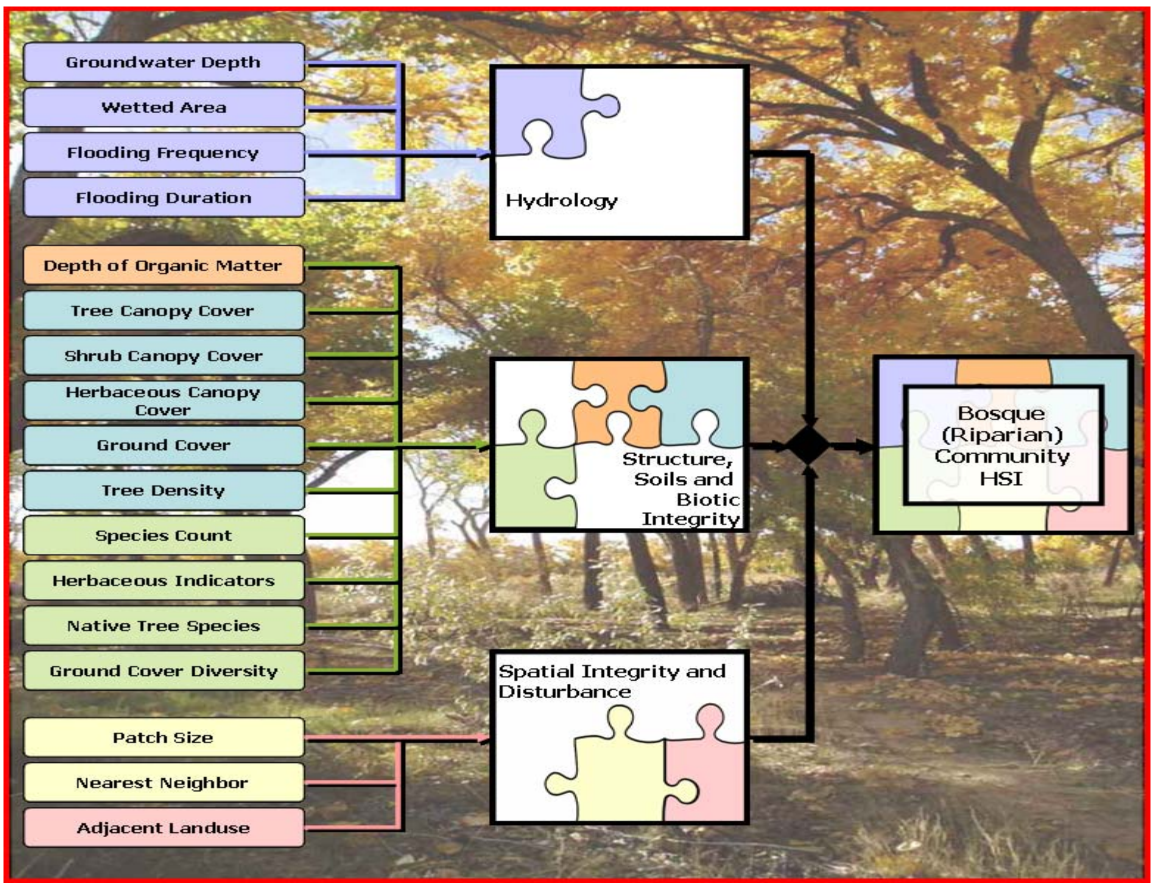
System-Wide Water Resources Program

A Bosque Riparian Community Index Model for the Middle Rio Grande, Albuquerque, New Mexico

Model Documentation

Kelly A. Burks-Copes and Antisa C. Webb

September 2012



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Final report

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Abstract

Over the last century, the Middle Rio Grande was subjected to significant anthropogenic pressures producing a highly degraded ecosystem that today is poised on the brink of collapse. In 2002, the U.S. Army Corps of Engineers (USACE) (Albuquerque District) was authorized to study the river and prepare an Environmental Assessment (EA), as required under the tenets of the National Environmental Policy Act (NEPA), to evaluate the effects of proposed ecosystem restoration alternatives on the watershed's significant resources. As part of the process, a multi-agency, multi-disciplinary evaluation team was established to formulate alternatives that would address three critical problems: 1) hydrological alterations, 2) bosque (riparian) ecosystem degradation, and 3) the loss of key ecological services to the surrounding community. Between 2005 and 2008, this team designed, calibrated, and applied a community-based index model for the bosque riparian ecosystem using field and spatial data gathered from 27 reference sample sites scattered across the watershed. This unique community was modeled using 23 individual variables combined into numerous predictive community functional components (i.e., Biotic Integrity, Hydrology, and Spatial context) capable of capturing the changes to ecosystem integrity in response to changes in land and water management activities proposed by the study. The intent of this document is to provide the scientific basis upon which the model was developed, and describe the 3-year-long process the team undertook to complete this effort. Although some results are presented here to demonstrate and verify the veracity of the model's calibration and subsequent outputs, readers interested in the application of this model on the Middle Rio Grande project must refer to a second report entitled, "Middle Rio Grande Bosque Ecosystem Restoration Feasibility Study Habitat Assessment Using Habitat Evaluation Procedures (HEP): Analyses, Results and Documentation," which is currently in preparation.

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Preface

This report documents a newly developed community-based index model [based on the Habitat Evaluation Procedures (HEP)] for the Middle Rio Grande River as it runs through the heart of Albuquerque, New Mexico.

The work described herein was conducted at the request of the U.S. Army Engineer District, Albuquerque, New Mexico. This report was prepared by Kelly A. Burks-Copes and Antisa C. Webb, U.S. Army Engineer Research and Development Center (ERDC), Environmental Laboratory (EL), Vicksburg, Mississippi. At the time of this report, Burks-Copes and Webb were ecologists in the Ecological Resources Branch (EE-E).

Many people contributed to the overall success of the production of the model documentation. The authors wish to thank the following people for their hard work and persistence during the intensive months over which the project was assessed: Jennifer Emerson (Bowhead Information Technology Services), Ondrea Hummel (Albuquerque District), and Seth Jones (Galveston District). They also thank Dr. Andrew Casper (ERDC), Kristine Nemec (formerly of the Kansas City District), and Todd Kaplan (Parametrix) for their comprehensive review of the report.

This report was prepared under the general supervision of Antisa C. Webb, Chief, EE-E and Dr. Edmond J. Russo, Chief, Ecosystem Evaluation and Engineering Division. At the time of publication of this report, Dr. Beth Fleming was Director of EL, COL Kevin J. Wilson was Commander of ERDC, and Dr. Jeffery P. Holland was Director of ERDC.

Unit Conversion Factors

Multiply	By	To Obtain
acres	4,046.873	square meters
cubic feet	0.02831685	cubic meters
feet	0.3048	meters
inches	0.0254	meters

1 Introduction

The desiccated landscape of the Southwest brings to mind tumbleweeds blowing along dusty grounds, ancient petroglyphs carved in dark caves and canyon walls, cattle skulls blanching under the merciless sun, and sidewinders slithering between the cacti. But running through these harsh and arid regions are ribbons of lush green, narrow corridors where rivers and streams, some ephemeral, some continually flowing, have slaked the parched desert to give rise to rare yet significant riparian ecosystems rich with life (Figure 1).

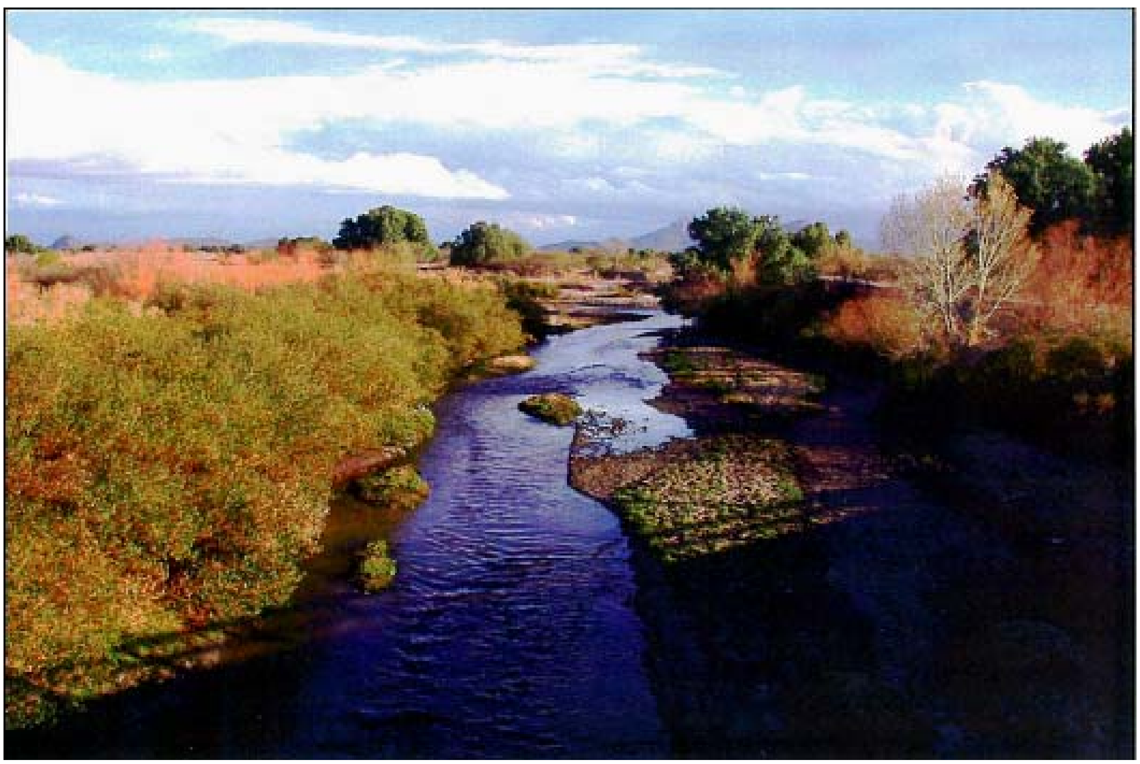

Figure 1. The arid Southwest often appears to be a desolate landscape, yet the presence of water offers an opportunity for fish and wildlife to find a niche.

While only occupying a mere fraction of the land area, these riparian corridors support both the largest concentrations of animal and plant life, and the majority of species diversity in the desert Southwest (Johnson and Jones 1977, Johnson et al. 1985, Knopf et al.1988, Ohmart et al. 1988, Dahl 1990, Johnson 1991, Minckley and Brown 1994, Noss et al. 1995, American Bird Conservancy 2008) (Figure 2).

Figure 2. Riparian corridors immediately adjacent to rivers in the arid Southwest offer lush habitat for fish and wildlife species.

Perhaps one of the more notable riparian ecosystems is found along the Rio Grande River. Arising in the San Juan Mountains of southwest Colorado, the river flows southwest through the middle of New Mexico and into Texas along the Texas-Mexico border emptying finally into the Gulf of Mexico. The Rio Grande offers one of the more ecologically complex, highly resilient, and culturally significant resources in the semi-arid western United States (Figure 3).

Historically, the Rio Grande was considered a braided, aggrading stream that meandered freely across a wide floodplain much larger than the current floodway ecosystem. As it meandered through time and space, the Rio Grande created and renewed the unique cottonwood riparian gallery forest communities. “Bosque” was the Spanish word that was used traditionally in the Southwest to describe these unique wooded riparian ecosystems (Figure 4).

Over the last century, the Middle Rio Grande was subjected to significant anthropogenic pressures producing a highly degraded ecosystem that today is poised on the brink of collapse. Water management and flow regulation along the Middle Rio Grande during this century have decoupled the linkage between the floodplain and the river and resulted in extensive changes in the riparian forest ecosystem (Ellis et al. 1996). The elimination of flooding has disrupted the functional integrity of these disconnected

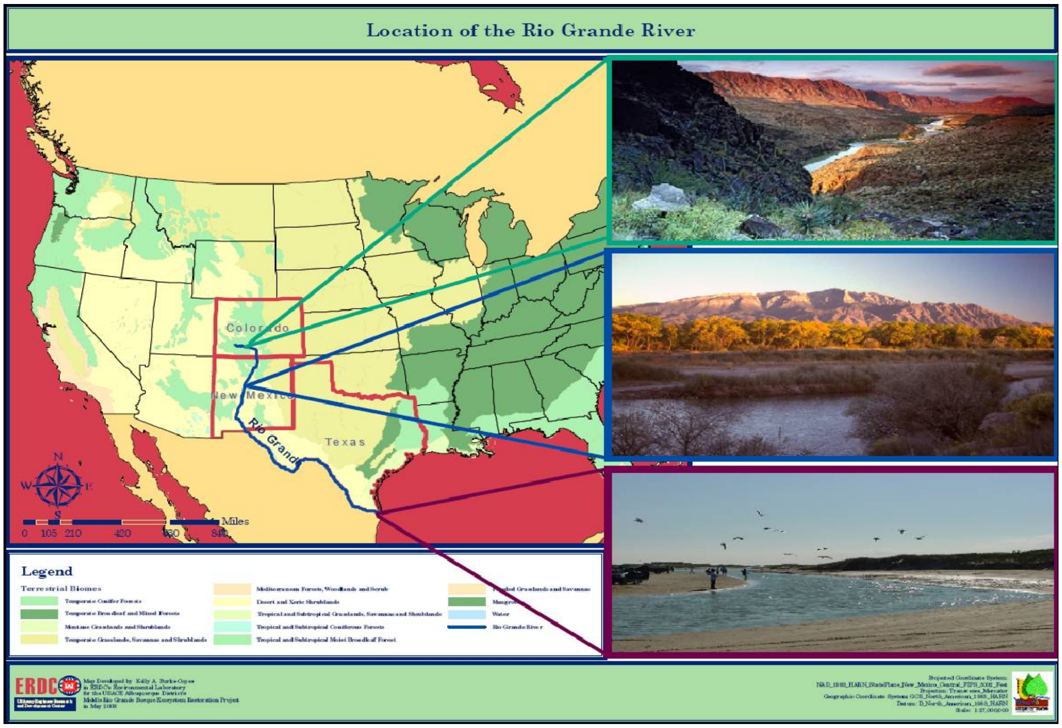

Figure 3. Location of the Rio Grande in the arid Southwest. Images capture the changing characteristics of the river as it flows from Colorado (top), through New Mexico (middle), and down into Texas (bottom) on its way to the Gulf of Mexico.

Figure 4. Cottonwood riparian gallery forests ablaze with fall colors along the Rio Grande.

forests and contributed to the decline of the Rio Grande Valley cottonwood. Estimates of riparian habitat loss in the Southwest range from 40% to 90% (Dahl 1990), and desert riparian habitats are considered to be one of this region's most endangered ecosystems (Minckley and Brown 1994, Noss et al. 1995). Decline of natural riparian structure and function of the bosque ecosystem was recognized in the 1980s as a major ecological change in the Middle Rio Grande valley (Hink and Ohmart 1984; Howe and Knopf 1991).

Study background

In 2002, the U.S. Army Corps of Engineers (USACE) Albuquerque District was authorized to conduct a reconnaissance study focused on a 17-mile-long stretch of the Rio Grande flowing through the city of Albuquerque, New Mexico (USACE 2002, 2003a, 2007b; Burks-Copes and Webb 2009) (Figure 5).

Figure 5. The Rio Grande flows through the heart of Albuquerque (seen in the background at the base of the mountains) on its way south to the Gulf of Mexico.

The reconnaissance study determined that there was a federal interest in participating in cost-shared feasibility studies to investigate ecosystem restoration, educational/ interpretive opportunities, and low-impact recreational opportunities for the Rio Grande floodway as it passes through Albuquerque, New Mexico. In 2004, a Feasibility Cost Sharing Agreement

was signed between the Middle Rio Grande Conservancy District (MRGCD), as the non-Federal Sponsor, and the USACE subsequently initiated the feasibility phase of the study. The purpose of this feasibility phase study was to determine if there was a Federal (USACE) interest in addressing the water resource problems and opportunities in the Middle Rio Grande area of Bernalillo County, New Mexico. [1]

In 2004, the USACE Albuquerque District contacted the U.S. Army Engineer Research and Development Center's Environmental Laboratory (ERDC-EL) to assist in these endeavors. The Middle Rio Grande study documentation identified and recommended effective, affordable, and environmentally sensitive ecosystem restoration features throughout the middle reach of the Rio Grande system (USACE 2002, 2003a, 2007b; Burks-Copes and Webb 2009). The goal was to provide the necessary engineering, economic, and environmental plans in a timely manner to establish viable projects that would be acceptable to the public, local sponsors, and USACE. The intent of this collaborative effort was to provide a framework for making decisions that would result in the restoration of the bosque ecosystem's structure and function.

The District has prepared an Environmental Assessment (EA), as required under the tenets of the National Environmental Policy Act (NEPA), to evaluate the benefits of the proposed ecosystem restoration measures in the study area (USACE 2011). As part of the process, a multi-agency evaluation team was established to (1) identify environmental issues and concerns; (2) evaluate the significance of fish and wildlife resources and select resources; (3) recommend and review environmental alternatives and studies; and (4) evaluate potential benefits of the proposed plans.

Purpose of the model

Planning, management, and policy decisions require information on the status, condition, and trends of these complex ecosystems and their components at various scales (e.g. local, regional, watershed, and system levels) to make reasonable and informed decisions about the planning management and conservation of sensitive or valued resources. One well-accepted solution has been to develop index models that assess ecosystems at varying scales. By definition, index models are comprehensive, multi-

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1 A complete list of acronyms and a glossary have been provided in Appendix A and Appendix B of this report.

scale, grounded in natural history, relevant and helpful, able to integrate terrestrial and aquatic environments, flexible and measurable (Andreasen et al. 2003). Determining the value of diverse biological resources in this study required a method that captured the complex biotic patterns of the landscape, rather than merely focusing on a single species habitat or suitability requirements within the study area. In effect, the Ecosystem Assessment Team (E-Team) made the decision to assess ecosystem benefits using community-based (functional) models rather than employing a series of species- or guild-based models.

Ecosystem functions are defined here as a series of processes that take place within an ecosystem. These include the storage of water, transformation of nutrients, growth of living matter, and diversity of plants, and they have value for the community itself, for surrounding ecosystems, and for people. Functions can be grouped broadly as habitat, hydrologic, water quality, and spatial integrity although these distinctions are somewhat arbitrary and simplistic. For example, the value of a wetland for recreation (hunting, fishing, bird watching) is a product of all the processes that work together to create and maintain the ecosystem. Not all communities perform all functions nor do they perform all functions equally well. The location and size of a community may determine what functions it will perform. For example, the geographic location may determine its habitat functions, and the location of a community within a watershed may determine its hydrologic or water-quality functional capacity. Many factors determine how well a community will perform these functions: climatic conditions, quantity and quality of water entering the system, and disturbances or alteration within the community or the surrounding landscape. Disturbances may be the result of natural conditions, such as an extended drought, or human activities, such as land clearing, dredging, or the introduction of invasive species.

The purpose of this modeling effort was to broadly capture existing, (baseline) conditions of the communities, and compare changes that would occur to the resources present given different project scenarios or alternatives under the standard USACE planning paradigm (USACE 2000). The model was used to facilitate plan formulation based upon project benefits. The purpose of the model was not to exhaustively capture the full range of all chemical, physical, and biological characteristics of the project area, but to provide tools for making comparisons between potential plans in order to select plans with the highest benefits. Planning decisions for the feasibility

study were subsequently made based on the results of the model applied with the well received and respected Habitat Evaluation Procedures (HEP) (U.S. Fish and Wildlife Service (USFWS) 1980a, 1980b, 1980c) framework.

Contribution to the planning effort

The model helped to characterize the baseline conditions (in a quantitative manner) of the numerous ecological resources throughout the watershed. The HEP method assisted the study team in the projection of change to fundamental ecosystem processes[1] (without which, ecosystem restoration itself could not happen), as the multiple alternative scenarios were proposed. The study team designed the HEP assessments to evaluate the future changes both in quantity (acres) and quality (community habitat suitability) of aquatic, wetland, and terrestrial ecosystems simultaneously. Outputs were calculated in terms of annualized changes anticipated over the life of the project (aka, period of analysis).

As noted earlier, the E-team was convened early in the evaluation process.[2] Scientists from ERDC-EL facilitated the efforts. Representatives from the Albuquerque District, USFWS, U.S. Forest Service (USFS), Bureau of Reclamation (BOR), Interstate Stream Commission (ISC), New Mexico Department of Game and Fish (NMDGF), New Mexico State Forestry Division (NMSFD), Natural Heritage New Mexico (NHNM), Rocky Mountain Research Station (RMRS), Middle Rio Grande Conservancy District (MRGCD), City of Albuquerque Open Space Program, University of New Mexico (UNM), and Parametrix consultants actively participated in the assessment process. The remainder of this document focuses on the development of the community-based Habitat Suitability Index (HSI) model developed by the E-Team for the Middle Rio Grande Bosque Ecosystem Restoration (MRGBER) feasibility study.

Planning model certification

As an aside, the USACE Planning Models Improvement Program (PMIP) was established to review, improve, and validate analytical tools and models for USACE Civil Works business programs. In May of 2005, the PMIP developed Engineering Circular (EC) 1105-2-407, Planning Models Improvement Program: Model Certification (USACE 2005). This EC

1 There are four fundamental ecosystem processes – water cycling, mineral cycling, solar energy flow, and community dynamics (aka, succession).

2 A list of E-Team participants can be found in Appendix D.

requires the use of certified models for all planning activities. It tasks the Planning Centers of Expertise to evaluate the technical soundness of all planning models based on theory and computational correctness. EC 1105-2-407 defines planning models as,

> *. . . any models and analytical tools that planners use to define water resources management problems and opportunities, to formulate potential alternatives to address the problems and take advantage of the opportunities, to evaluate potential effects of alternatives and to support decision-making.*

Clearly, the community-based HSI model developed for the study must be either certified or approved for one-time use. The Albuquerque District initiated this review in 2008 and received a memo from the USACE Eco-PCX granting one-time-use approval in April 2009 (Appendix C). Information necessary to facilitate model certification/one-time-use approval is outlined in Table 2 of EC 1105-2-407 (pages 9-11). To assist the reviewers in the certification effort for the model, the authors have developed an appendix to crosswalk the EC checklist requirements and this report (Appendix C).

For purposes of model certification, it is important to note that the model must be formally certified or approved for one-time use, but the methodology under which it is applied (i.e., HEP) does not require certification, as it is considered part of the application process. HEP in particular has been specifically addressed in the EC:

> *The Habitat Evaluation Procedure (HEP) is an established approach to assessment of natural resources, developed by the US Fish and Wildlife Service in conjunction with other agencies. The HEP approach has been well documented and is approved for use in Corps projects as an assessment framework that combines resource quality and quantity over time, and is appropriate throughout the United States." (refer to Attachment 3, page 22, of the EC)*

The authors used the newly developed **Habitat Evaluation and Assessment Tools (HEAT)** tool (Burks-Copes et al., in preparation) to automate the calculation of habitat units for the MRGBER study. This software is not a "shortcut" to HEP modeling, or a model in and of itself, but rather a series of computer-based programming modules that accept the

input of mathematical details and data comprising the index model, and through their applications in the HEP or the Hydrogeomorphic Wetland Assessment (HGM) processes, calculates the outputs in responses to parameterized alternative conditions. The **HEAT** software contains two separate programming modules – one used for HEP applications referred to as the **EXpert Habitat Evaluation Procedures (EXHEP)** module, and a second used in HGM applications referred to as the **EXpert Hydrogeomorphic Approach to Wetland Assessments (EXHGM)** modules. The authors used the **EXHEP** module to calculate outputs for the MRGBER study. The developers of the **HEAT** tool (including both the **EXHEP** and **EXHGM** modules themselves) are pursuing certification through a separate initiative, and hope to complete this process in the next year barring unforeseen financial and institutional problems.

The authors used the **IWR Planning Suite**[1] to run the cost analyses for the restoration plans in the MRGBER study, which was certified in 2008.

Report objectives

This document describes the development of the community-based HSI model for the bosque (riparian) community located along the banks of the Middle Rio Grande River running through the heart of Albuquerque, New Mexico. The objectives of this report are to:

1. Briefly characterize the Middle Rio Grande watershed, within the study area, in central New Mexico;
2. Characterize the bosque community used in the HEP evaluations and its applicable cover types;
3. Present the relationships of habitat maintenance components for the index model;
4. Define and justify the selection of assessment variables and their associated curve calibrations used to characterize the components of the model; and
5. Provide critical information to reviewers to facilitate the future certification/one-time-use approval of the index model.

Report structure

This report is organized in the following manner. *Chapter 1* provides the background, objectives, and organization of the document. *Chapter 2*

1 http://www.pmcl.com/iwrplan/

provides a brief overview of HEP, and the method in which the model will be applied, including the procedures recommended for development and application of the HSI model. *Chapter 3* discusses the evolution of the model in terms of conceptual development, offers critical insight into the characterization of the community, provides details regarding the key functional components of the HSI model in particular (and its mathematical representations), and then concludes with the construction and testing of the HSI model over the last three years. *Chapter 4* offers insight into the HSI model's calibration approach, and offers descriptions of the assessment variables used to characterize the community including definitions, rationale for selection, and specific sampling guidelines. *Chapter 5* summarizes the model findings and discusses future research initiatives to expand its utility and context.

Several appendices are attached to this document. Appendix A is a list of acronyms used throughout this document. Appendix B is a glossary of commonly used terms regarding the HSI model and the HEP evaluation. Appendix C offers a crosswalk between the standard requirements and information necessary to certify/approve the use of the model. Appendix D contains a point of contact for the formal minutes documenting the decisions made during the initial model development workshops and offers a complete list of E-Team participants. Appendix E provides individual index curves for the variables used in the model. Appendix F offers field data protocols and a crosswalk between the region's more notable vegetative classification system (Hink and Omart 1984) and the classification used in the index model described here. Appendix E contains the model review forms and documents the review comments provided by the Albuquerque District and the workshop participants as the planning study proceeds through review.

2 HEP Overview

The HEP process

The HEP methodology is an environmental accounting process developed to appraise habitat suitability for fish and wildlife species in the face of potential change (USFWS 1980a, 1980b, 1980c). Designed to predict the response of habitat parameters in a quantifiable fashion, HEP is an objective, reliable, and well-documented process used nationwide to generate environmental outputs for all levels of proposed projects and monitoring operations in the natural resources arena. When applied correctly, HEP provides an impartial look at environmental effects, and delivers measurable products to the user for comparative analysis.

In HEP, a Suitability Index (SI) is a mathematical relationship that reflects a species' or community's sensitivity to a change in a limiting factor (i.e., variable) within the habitat type. These suitability relationships are depicted using scatter plots and bar charts (i.e., suitability curves). The SI value (Y-axis) ranges from 0.0 to 1.0, where an SI = 0.0 represents a variable that is extremely limiting, and an SI = 1.0 represents a variable in abundance (not limiting) for the species or community. In HEP, an HSI model is a quantitative estimate of habitat conditions for an evaluation species or community. HSI models combine the SIs of measurable variables into a formula depicting the limiting characteristics of the site for the species/community on a scale of 0.0 (unsuitable) to 1.0 (optimal).

Statement of limitations

The HEP methodology can provide a rational, supportable, focused, and traceable evaluation of habitat functionality. However, the user must understand the basic HEP tenets as defined in supporting literature (USFWS 1980a, 1980b, 1980c) prior to attempting application of the methodology. Outcomes derived under HEP are dependent on the user's ability to predict future conditions and the reliability of resource data used. The user should understand that HEP is not a carrying-capacity model and cannot comprehensively predict future species and species population sizes. Furthermore, HEP is not designed to compare across evaluation elements (e.g. compare prairie habitat to forest habitat). The user should not expect HEP to provide the only predictive environmental

response to project development scenarios, and should understand the limitations of the methodology's response to predictive evaluations prior to its application.[1]

HSI Models in HEP

Users can select several indicator species to evaluate overall site fitness. In the HEP process, species are often selected on the basis of their ecological, recreational, spiritual, or economic value. In other instances, species are chosen for their representative value (i.e., one species can "represent" a group or guild of species which have similar habitat requirements). Most of these species can, in turn, be described using single or multiple habitat models and a single HSI mathematical formula. In some studies, several cover types are included in an HSI model to accurately reflect the complex interdependencies critical to the species' or community's existence. Regardless of the number of cover types incorporated within an HSI model, any HSI model based on the existence of a single life requisite requirement (e.g. food, water, cover or reproduction), uses a single formula to describe that relationship.

Some species are insufficiently examined using the simplistic approach. In these instances, a more detailed model can emphasize critical life requisites, increase limiting factor sensitivity, and improve the predictive power of the analysis. Multiple habitats and formulas are often necessary to calculate the habitat suitability of these more comprehensive HSI models. The second type of HSI model is used to capture the juxtaposition of habitats, essential dependencies, and performance requirements such as reproduction, roosting needs, escape cover demands, or winter cover that describe the sensitivity of a species or community. Multiple formula models require more extensive processing to evaluate habitat conditions.

Habitat Units in HEP

HSI models can be tailored to a particular situation or application and adapted to meet the level of effort desired by the user. Thus, a single model (or a series of inter-related models) can be adapted to reflect a site's response to a particular design at any scale (e.g., species, community, ecosystem, regional, or global dimensions). Several agencies and

1 Additional support for the HEP methodology has been provided in Table C1, under the section titled "Technical Quality," sub-section a, "Theory."

organizations have adapted the basic HEP methodology for their specific needs in this manner (Inglis et al. 2006, Gillenwater et al. 2006, Ahmadi-Nedushan et al. 2006). HEP combines both the habitat quality (HSI) and quantity of a site (measured in acres) to generate a measure of change referred to as Habitat Units (HUs). Once the HSI and habitat quantities have been determined, the HU values can be mathematically derived with the following equation: HU = HSI x Area (acres). Under the HEP methodology, one HU is equivalent to 1 acre of optimal habitat for a given species or community.

Capturing changes over time in HEP applications

In studies spanning several years, Target Years (TYs) must be identified early in the process. Target Years are units of time measurements used in HEP that allow users to anticipate and direct significant changes (in area or quality) within the project (or site). As a rule, the baseline TY is always TY = 0, where the baseline year is defined as a point in time before proposed changes would be implemented. As a second rule, there must always be a TY = 1 and a TY = X_2. TY1 is the first year that land- and water-use conditions are expected to deviate from baseline conditions. TYX_2 designates the ending target year. A new target year must be assigned for each year the user intends to develop or evaluate change within the site or project. The habitat conditions (quality and quantity) described for each TY are the expected conditions at the end of that year. It is important to maintain the same target years in both the environmental and economic analyses, and between the baseline and future analyses. In studies focused on the long-term effects, HUs generated for indicator species are estimated for several TYs to reflect the life of the project (aka, period of analysis). In such analyses, future habitat conditions can be estimated for both the without-project (e.g., No Action Plan) and with-project conditions. Projected long-term effects of the project are reported in terms of Average Annual Habitat Units (AAHUs) values. Based on the AAHU outcomes, alternative designs can be formulated and trade-off analyses can be simulated to promote environmental optimization.

Developing index models for HEP

Based on the USFWS's Ecological Service Manual (ESM) series on HEP (USFWS 1980a, 1980b, 1980c), 11 steps are involved in the application of HEP when assessing an environmental project:

1. Build a multi-disciplinary E-Team;
2. Define the project;
3. Map the site's cover types (CTs);
4. Select, modify, and/or create index model(s);
5. Conduct field sampling;
6. Perform data management and statistical analyses;
7. Calculate baseline conditions;
8. Set goals and objectives, and define project life and TYs;
9. Generate without-project (WOP) conditions and calculate outputs;
10. Generate with-project (WP) conditions and calculate outputs; and
11. Report the results of the analyses.

However, this document only addresses the development of the model used in the HEP process for this study. For further detail on each of the 11 steps, refer to the habitat assessment report for the MRGBER study (Burks-Copes and Webb, in preparation).

Steps in model development

Community assessment was identified as a priority for the District's upcoming feasibility study. However, few HSI community models were published and available for application. ERDC-EL proposed a strategy to the District to develop community models for the MRGBER study. The strategy entailed five steps:

1. Compile all available information that could be used to characterize the communities of concern.
2. Convene an expert panel in a workshop setting to examine this material and generate a list of significant resources and common characteristics (land cover classes, topography, hydrology, physical processes) of the system that could be combined in a meaningful manner to "model" the communities. In the workshop, it was important to outline study goals and objectives and then identify the desired model endpoints (e.g., outputs of the model). It was also critical for the participants to identify the limiting factors present in the project area relative to the model endpoints and habitat requirements. The outcome of the workshop was a series of mathematical formulas that were identified as functional components (e.g., Hydrology, Vegetative Structure, Diversity, Connectivity, Disturbance, etc.). These formulas were comprised of variables that were:

    a. biologically, ecologically, or functionally meaningful for the subject,

b. easily measured or estimated,
c. able to have scores assigned for past and future conditions,
d. related to an action that could be taken or a change expected to occur,
e. were influenced by planning and management actions, and
f. independent from other variables in each model.

3. Develop both a field and a spatial data collection protocol (using Geographic Information Systems (GIS)) and, in turn, use these strategies to collect all necessary data and apply these data to the model in both the “reference” setting and on the proposed project area.
4. Present the model results to an E-Team and revise/recalibrate the model based on their experiences, any additional and relevant regional data, and application directives.
5. Submit the model to both internal ERDC/District/E-Team review and then request review from the initial expert panel that participated in the original workshop, as well as solicit review from independent regional experts who were not included in the model development and application process.

Model review process

The process described in Appendix G is currently being implemented to assure that quality control is an integral part of model development and document production. In essence, a laboratory-directed model review process is underway, one that involves both direct-line supervisors of the model authors, and peer reviews by researchers and planning personnel outside of the model development team. It is important to note that the District will be responsible for incorporating the ERDC-EL documents into their integrated feasibility study reports and documents.

3 Community-based HSI Models

As described earlier in *Chapter 2* of this report, index models can quantify the effects of change in a given ecosystem setting and can be used to account for restoration gains under the HEP assessment paradigm. This chapter describes the bosque (riparian) community found along the middle Rio Grande in central New Mexico (running through Albuquerque), and describes the process by which the E-Team developed and tested the resultant community-based HSI model. General descriptions of both the variables and their relationships to one another are provided for the model as well. The goal of this chapter is to characterize the E-Team's effort to capture the character of the bosque ecosystem using a traditional index model-based approach.

Model development workshops

A series of 10 workshops were held over the course of three years (2005-2008) to develop the model and characterize baseline conditions of the study area prior to plan formulation and alternative assessment for the ecosystem restoration study. A community-based index model (**Bosque Riparian Community**) was developed under this paradigm. Several federal, state, and local agencies, as well as local and regional experts from the stakeholder organizations, and private consultants, participated in the model workshops.[1] In the first workshop, the E-Team was briefed on the project scope and opportunities by the District planners. Land and water management activities (e.g., hydrologic alterations, urban development, and agricultural production) were identified as the system's key anthropogenic drivers. The stressors (i.e., physical, chemical and biological changes to system structure and function) were identified and grouped into four categories: 1) hydrologic alteration, 2) geomorphic and topographic alteration, 3) urban encroachment and agricultural use, and 4) exotic species introductions. Each stressor altered ecosystem integrity[2] within a water, soils, habitat and/or landscape context. For example, hydrologic alterations to the channel have caused changes not only in flooding

[1] A list of E-Team participants can be found in *Appendix D*.

[2] The authors prescribe to the Society for Ecological Restoration International's (2004) definition of *ecosystem integrity* here, which has been defined as "the state or condition of an ecosystem that displays the biodiversity characteristic of the reference, such as species composition and community structure, and is fully capable of sustaining normal ecosystem functioning."

frequency and duration, but have altered ecosystem function and structure across the basin. Urban encroachment has exacerbated these problems by reducing infiltration, increasing stormwater runoff, and increasing disturbance regimes system-wide. These changes have ultimately led to opportunities for exotic species invasions reducing spatial complexity on a landscape scale. The direct and indirect effects of these alterations are as obvious as they are numerous – reduced hydrologic pulsing, reduced sediment transport, fragmentation, and loss of biodiversity.

Coupling conceptual modeling and index modeling

Conceptual models are proving to be an innovative approach to organize, communicate, and facilitate analysis of natural resources at the landscape scale (Harwell et al. 1999, Turner et al. 2001, Henderson and O'Neil 2004, Davis et al. 2005, Ogden et al 2005, Watzin et al. 2005, Alvarez-Rogel et al. 2006). By definition, a conceptual model is a representation of relationships among natural forces, factors, and human activities believed to impact, influence, or lead to an interim or final ecological condition (Harwell et al. 1999, Henderson and O'Neil 2004). In most instances these models are presented as qualitative or descriptive narratives and are illustrated by influence diagrams that depict the causal relationships among natural forces and human activities that produce changes in systems (Harwell et al. 1999, Turner et al. 2001, Ogden et al. 2005, Alvarez-Rogel et al. 2006). No doubt, conceptual models provide a forum in which individuals of multiple disciplines representing various agencies and outside interests can efficiently and effectively characterize the system and predict its response to potential alternatives in a descriptive manner. In theory and practice, conceptual models have proved an invaluable tool to focus stakeholders on developing ecosystem restoration goals given recognized drivers and stressors. These in turn are translated into essential ecosystem characteristics that can be established as targets for modeling activities.

For purposes of this study, a systematic framework was developed that coupled the traditional USACE planning process with an index modeling approach derived from a sound conceptual understanding of ecological principles and ecological risk assessment that characterized ecosystem integrity across spatial and temporal scales, organizational hierarchy, and ecosystem types, yet adapted to the project's specific environmental goals. Ideally, the development of conceptual models involves a close linkage with community-index modeling, and produces quantitative assessment of systematic ecological responses to planning scenarios (Figure 6).

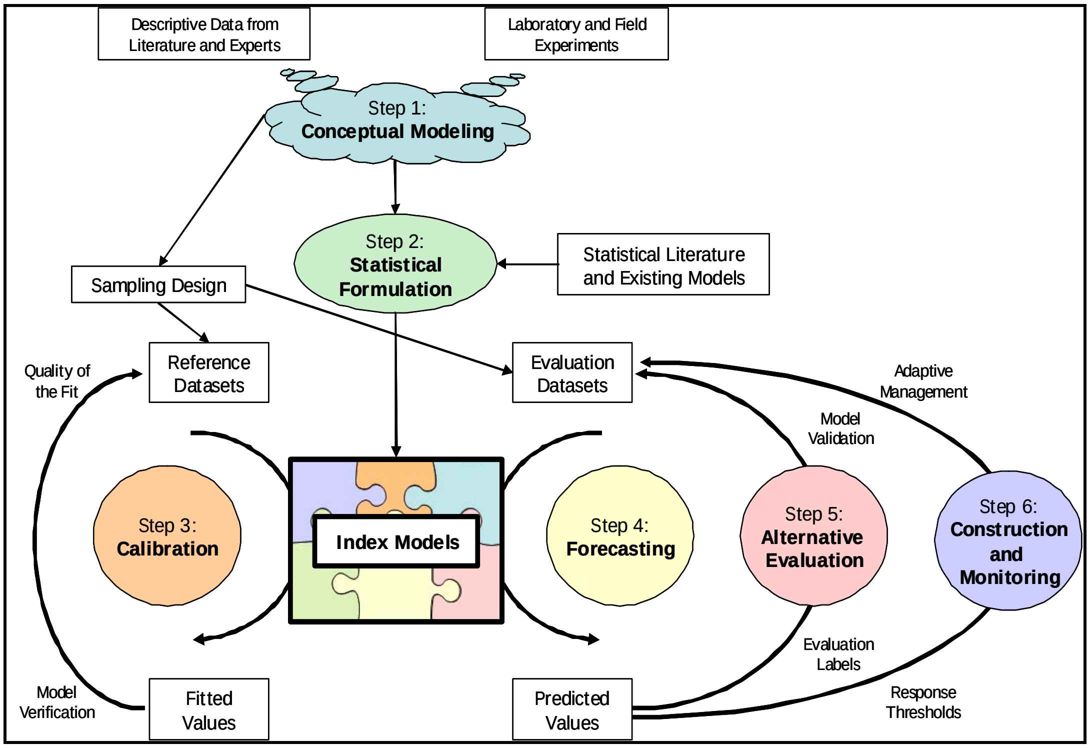

Figure 6. Overview of the successive steps (1-6) of the community-based index model building and application process for ecosystem restoration, where two data sets (one for calibration and one for alternative evaluations) are used (adapted from Guisan and Zimmerman 2000).[1]

Under this MRGBER modeling paradigm, conceptual modeling led to the choice of an appropriate scale for conducting the analysis and to the selection of ecologically meaningful explanatory variables for the subsequent environmental (index) modeling efforts. The model was calibrated using reference-based conditions and modified when the application dictated a necessary change.

As a first step in the index model development process, ERDC-EL developed a conceptual model to illustrate the relationships between these system-wide drivers and stressors and tried to highlight the ecosystem responses to these pressures across the entire Rio Grande-Albuquerque watershed (Figure 7).

Conceptually speaking, the “Significant Ecosystem Components” (water, soils, habitat, and landscape) were characterized by parameters responsive to project design. These parameters or variables (hydroperiod, vegetative

[1] It is important to note here that the same models used to evaluate alternatives should be used in the future to monitor the restored ecosystem and generate response thresholds to trigger adaptive management under the indicated feedback mechanism. As such, the District can use the models developed early on in the process to adaptively manage the system over the long term.

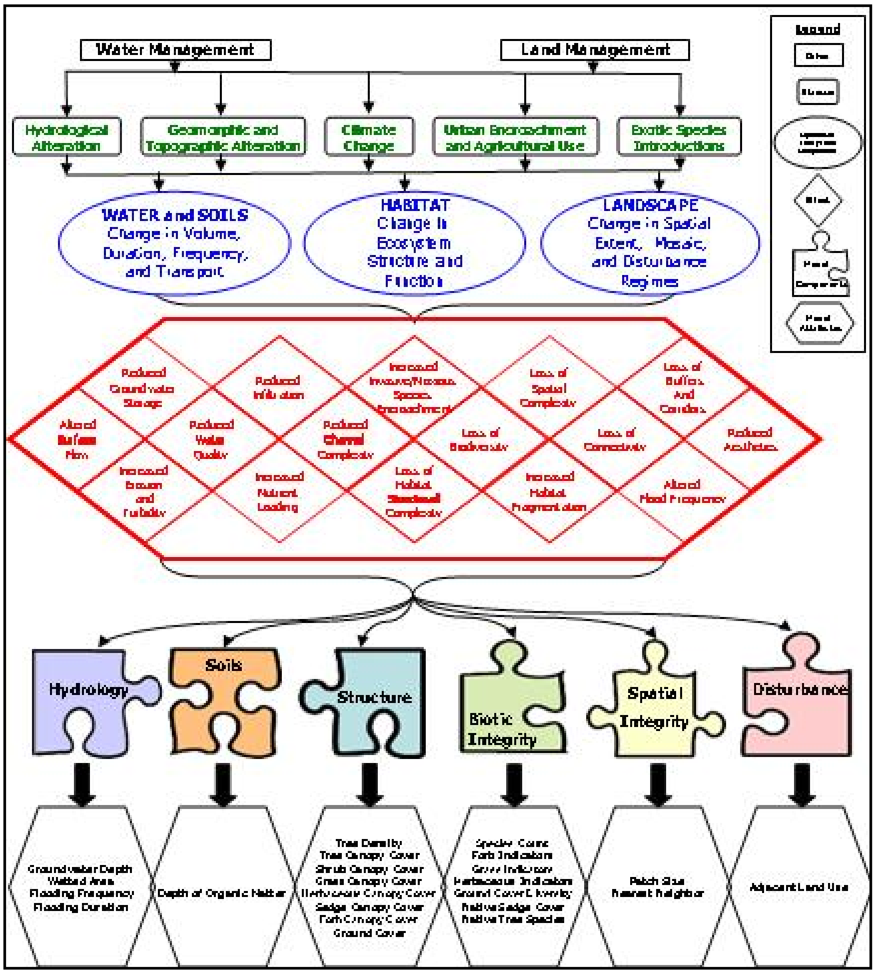

Figure 7. A conceptual model for the MRGBER.

cover, disturbance, etc.) were grouped in a meaningful manner to quantify the functionality of the community in the face of change based on expert opinion and scientific literature. The effort to combine the variables in mathematical algorithms could then be viewed as community index modeling under the HEP paradigm. For purposes of organization, the community-based index model was constructed from combinations of components – an analogy used was one of puzzle building. The individual model components were represented as “pieces” of the ecosystem puzzle, that, when combined, captured the essence of the system’s functionality (Figure 8).

Vegetation communities in the area ranged from riparian forests, shrub-lands, savannahs, meadows, and open marshes to the river itself. Out of this effort a bosque (riparian zone) community model arose. Subsequent refinement of the model led to the identification of contributing ecosystem components, and a description of associated variables (with suggested

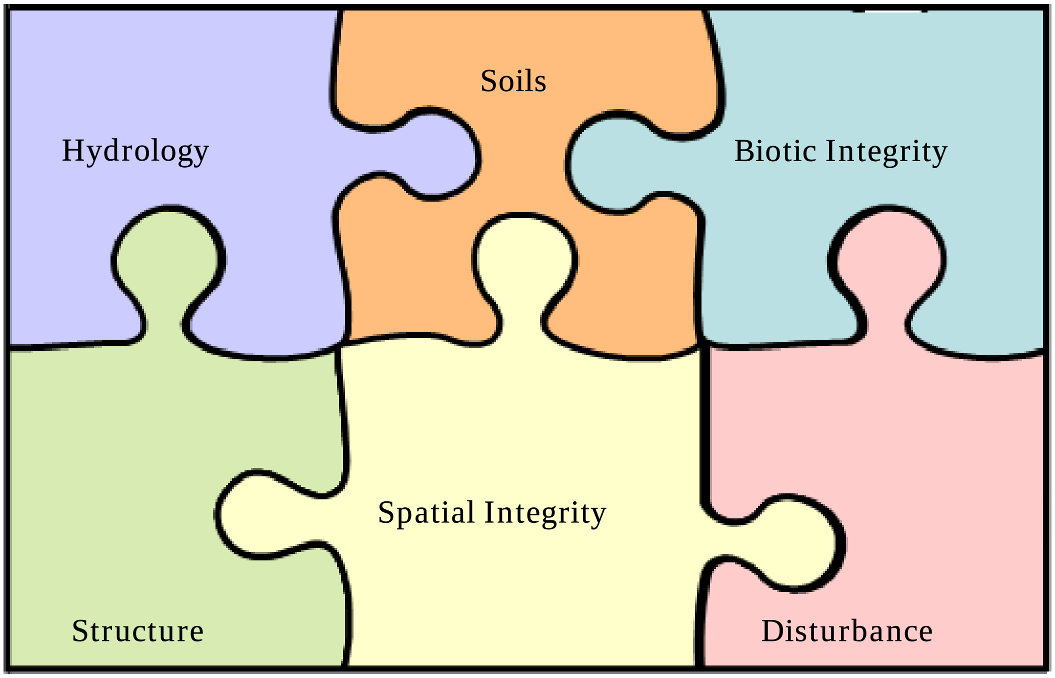

Figure 8. Within the conceptual modeling building framework, the various model components (color-coded for organization purposes) are pieced together to capture the essence of community functionality using the ecosystem puzzle analogy.

sampling protocols) that can be used to measure ecosystem restoration benefits. The accuracy and utility of the proposed model was "tested" (e.g., validated and verified) with specific field and planning exercises on the District's ongoing ecosystem restoration feasibility study. The application led ERDC-EL to modify the model several times over the course of the study to accommodate broader planning specifications.

Bosque riparian community characterization

River systems and their attendant wetland/riparian communities, referred to as "bosques" in New Mexico (derived from the Spanish word for forest), provide significant resources for both humans and wildlife in the semi-arid western United States. Water resource management activities –diversions, dams, levees, drains, channelization and jetty jack installation–by Federal agencies and other entities, as well as ongoing urbanization, have significantly altered the hydrologic system and degraded the ecosystem function and value of the Rio Grande within New Mexico. The bosque is unique; it is a thin line of significant riparian habitat in an arid landscape of the Southwest. The habitat quality, although diminished over the past few decades, still remains one of the most significant in the region. The uniqueness of the Rio Grande system and its critical value as wildlife habitat emphasize its significance as a critical resource. Over 300 species of birds, mammals,

amphibians, and reptiles live in the bosque - more than double those found in any other major ecosystem in the state. In fact, the bosque serves as a critical migration route for thousands of North American birds moving along the Central Flyway.

Functional riparian systems such as the Middle Rio Grande bosque are becoming increasingly rare in the Southwest. Such systems located in the center of an urban area are rarer still. The Rio Grande with its bosque is a green ribbon that weaves together various communities of the Albuquerque metropolitan area both figuratively and physically, connecting the present-day urbanites to the original inhabitants in the region. For decades the bosque has provided ecosystem services (for example, water filtration, urban heat island mitigation, etc.) for Albuquerque and its neighboring communities. It also continues to provide unique aesthetic, cultural, educational, and recreational opportunities for citizens and visitors to the region. The health of the region's many species of wildlife, as well as its human inhabitants, rests on the long-term health and viability of the Rio Grande bosque. The sections that follow detail the classic character of New Mexico's bosque as it peppers the banks along the Rio Grande flowing through the heart of the city.

Reference domain for the models

It is important to note that the model developed in this study is applicable to a specific domain: the riparian habitat between the levees along the 17-mile stretch of the Rio Grande flowing through Albuquerque, New Mexico (Figure 9).

The outflow of the city's North Diversion Channel forms the northern boundary of each model's domain, while the southern boundary is formed by the northern limits of the Pueblo of Isleta. The area is delimited on the east and west by the flood control levees, although the areas adjacent to the levees within the original floodplain have been considered in the calibration of the model.

The study area roughly corresponds to the *Rio Grande Valley State Park*, which runs through the center of Albuquerque and the County of Bernalillo. The park was dedicated for public uses and conservation purposes, and is one of the last intact cottonwood gallery forests along the Rio Grande. The bosque forest therein is one of the most biologically rich areas in the state and arguably one of the largest cottonwood riparian galleries in the south-western United States (USACE 2002, 2003a, 2007b, 2011; Burks-Copes and Webb 2009).

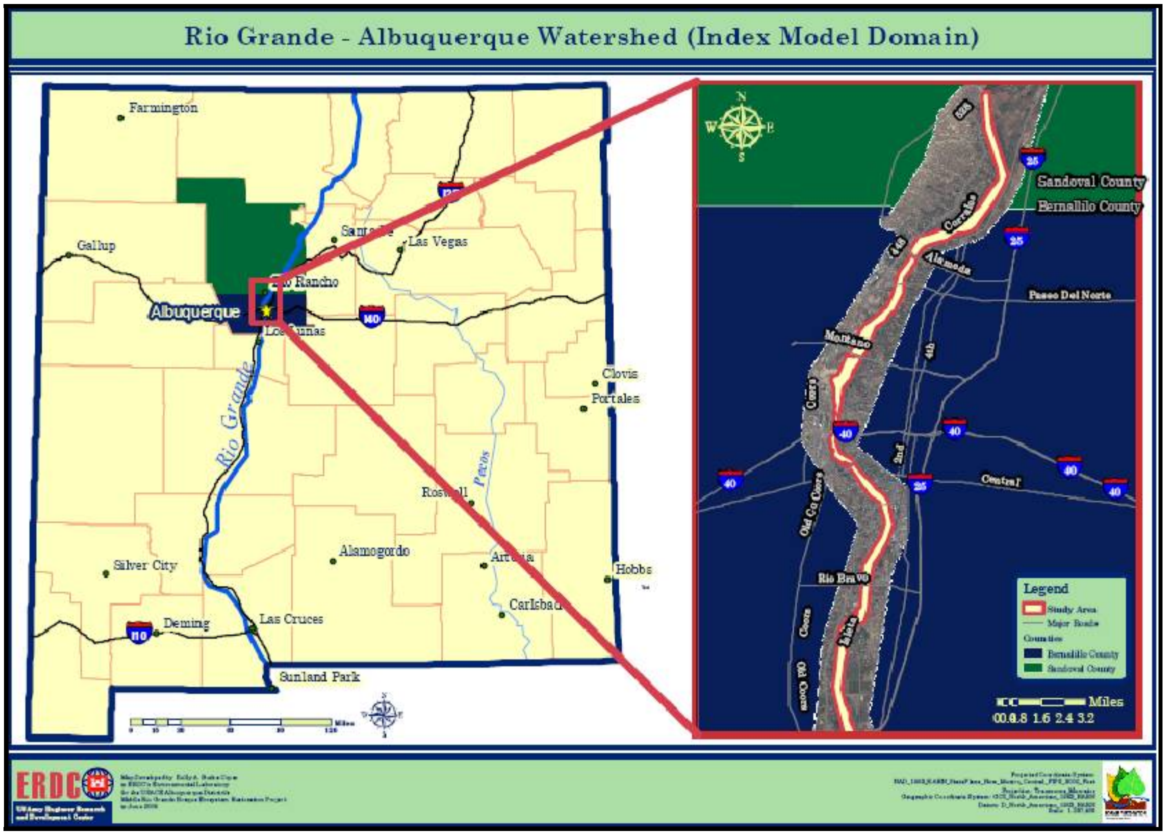

Figure 9. Reference domain for the Rio Grande-Albuquerque watershed index model.

The area is maintained as a part of the Middle Rio Grande Flood Control Acts of 1948 and 1950 and is within the Facilities of the *Middle Rio Grande Project* (USACE 2002, 2003a, 2007b, 2011; Burks-Copes et al. 2009). The bosque area within Albuquerque was designated as the *Rio Grande Valley State Park* through the Park Act of 1983 and is cooperatively managed by the City of Albuquerque Open Space Department and the MRGCD (Figure 10). The bosque within Corrales is designated as the *Corrales Bosque Preserve* and is cooperatively managed by the Village of Corrales and the Corrales Bosque Commission through an agreement with the MRGCD. *Sandia Pueblo* lands are managed by the Native American Pueblo Tribe.

By definition, the model presented here can be applied within this physical and ecological domain. In all likelihood, the model can be used several miles upstream or downstream of this narrowly defined area. However, any attempt to port this model to other locations outside this domain will likely require a recalibration of the parameters and algorithms associated with the tool.

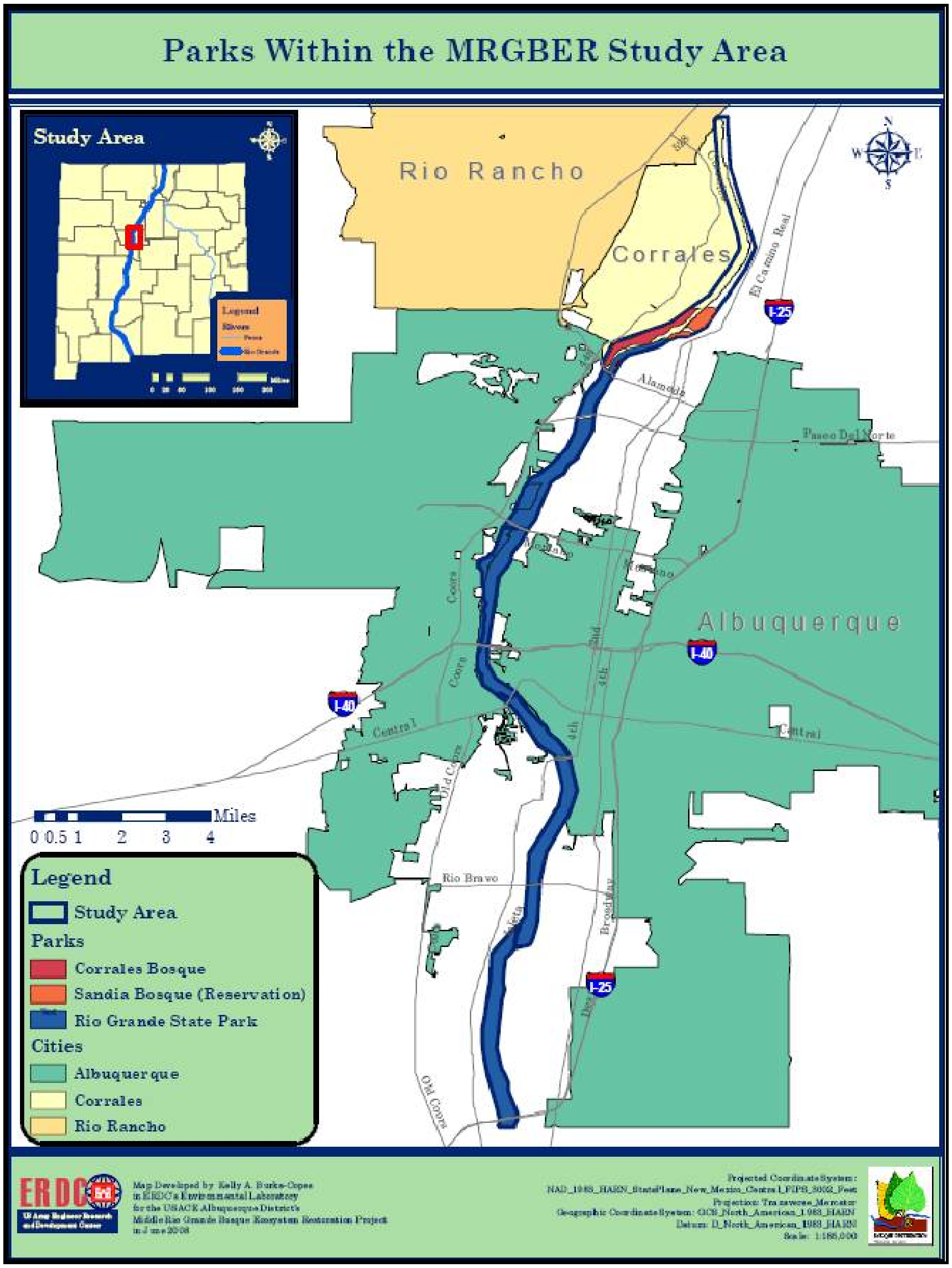

Figure 10. Parks maintained inside the MRGBER Study Area.

Climatic characterization

Albuquerque's climate is usually sunny and dry, with low relative humidity.[1] Brilliant sunshine defines the region, averaging more than 300 days a year; periods of variably mid- and high-level cloudiness temper

1 Information retrieved from Wikipedia (http://en.wikipedia.org/wiki/Albuquerque,_New_Mexico#Climate) in September of 2008.

the sun at other times. Extended cloudiness is rare. The city has four distinct seasons, but the heat and cold are mild compared to the extremes that occur more commonly in other parts of the country.

Winters are rather brief but definite; daytime highs range from the mid-40s to upper 50s Fahrenheit, while the overnight lows drop into the low 20s to near 30 by sunrise; nights are often colder in the valley and uppermost foothills by several degrees, or during cold frontal passages from the Great Basin or Rocky Mountains (Table 1).

Table 1. Weather averages for Albuquerque, New Mexico.[1]

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Record high	70°F (21°C)	78°F (26°C)	89°F (32°C)	89°F (32°C)	98°F (37°C)	107°F (42°C)	105°F (41°C)	101°F (38°C)	100°F (38°C)	91°F (33°C)	77°F (25°C)	72°F (22°C)
Average high	48°F (9°C)	55°F (13°C)	62°F (17°C)	71°F (22°C)	80°F (27°C)	90°F (32°C)	92°F (33°C)	89°F (32°C)	82°F (28°C)	71°F (22°C)	57°F (14°C)	48°F (9°C)
Average low	24°F (-4°C)	28°F (-2°C)	34°F (1°C)	41°F (5°C)	50°F (10°C)	59°F (15°C)	65°F (18°C)	63°F (17°C)	56°F (13°C)	44°F (7°C)	32°F (0°C)	24°F (-4°C)
Record low	-17°F (-27°C)	-6°F (-21°C)	6°F (-14°C)	12°F (-11°C)	28°F (-2°C)	37°F (3°C)	44°F (7°C)	45°F (7°C)	30°F (-1°C)	21°F (-6°C)	-7°F (-22°C)	-8°F (-22°C)
Precipitation inches (mm)	0.49 (12.4)	0.44 (11.2)	0.61 (15.5)	0.50 (12.7)	0.60 (15.2)	0.65 (16.5)	1.27 (32.3)	1.73 (43.9)	1.07 (27.2)	1.00 (25.4)	0.62 (15.7)	0.49 (12.4)

The occasional snowfall, associated with low pressure areas, fronts, and troughs, often melts by the mid-afternoon; over half of the scant winter moisture occurs in the form of light rain showers, usually brief in duration. In the much higher and colder Sandia Mountains, moisture falls as snow; in many years, there is enough snow to create good skiing conditions at the local ski area.

Springtime starts off windy and cool, sometimes unsettled, with some rain and even light snow, though spring is usually the driest part of the year in Albuquerque. March and April tend to see many days with the wind blowing at 20 to 30 mph (32 to 48 km/h), and afternoon gusts can produce periods of blowing sand and dust. In May, the winds tend to subside, as temperatures start to feel like summer. Summer daytime highs range from the upper 80s to the upper 90s, while dropping into the low 60s to low 70s overnight; the valley and uppermost foothills are often several degrees cooler. Fall sees mild days and cool nights with less rain, though the weather can be more unsettled closer to winter.

1 Weather.com - Monthly Averages for Albuquerque, NM (SEPTEMBER 2008).

Albuquerque's climate is classified as arid (BWk or BWh, depending on the particular scheme of the Köppen climate classification system[1] one uses), meaning average annual precipitation is less than half of evaporation, and the mean temperature of the coldest month is above freezing (32°F). Only the wettest areas of the Sandia foothills are barely semi-arid, where precipitation is more than half of, but still less than, evaporation; such areas are localized and usually lie above 6,000 ft (1,800 m) in elevation and often in arroyo drainages, signified by a slightly denser, taller growth of evergreen oak - juniper - pinon chaparral and rarely, woodland, often mixed with taller desert grasses. These elevated foothill areas still border arid areas, best described as desert grassland or desert shrub, on their west sides.

The mountains and highlands to the north and east of the city create a "rain shadow" effect, due to the drying of descending air movements; the city usually receives very little rain or snow, averaging 8-9 in. (216 mm) of precipitation per year. Valley and west mesa areas, farther from the mountains, are drier, averaging 6-8 in. of annual precipitation; the Sandia foothills tend to lift any available moisture, enhancing precipitation to about 10-17 in. annually. Most precipitation occurs during the summer monsoon season (also called a chubasco in Mexico), typically starting in early July and ending in mid-September.

Vegetative characterization

An ecosystem's vegetation at any given time is determined by a variety of factors, including climate, topography, soils, proximity to bedrock, drainage, occurrence of fire, and human activities. Because of the temporal and spatial variability of these factors and the sensitivity of different forms of vegetation to these factors, the system's character is one of dynamic, changing juxtapositions (i.e., a fluid mosaic). For details regarding the historical conditions of the study area, refer to the District's documents (USACE 2002, 2003a, 2007b, 2011; Burks-Copes et al. 2009). Of particular concern for this effort is the state of the vegetative communities within the model domain (Figure 11).

To fully quantify the habitat conditions for this area, it is useful to divide the project into manageable sections and quantify these in terms of acres per habitat type. This process, referred to as "cover typing," allows the user to define the differences between vegetative "types" (e.g., forest, shrublands,

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[1] http://en.wikipedia.org/wiki/K%C3%B6ppen_climate_classification (September 2008).

Figure 11. At stake - the dwindling cottonwood-dominated bosque community.[1]

wet/dry meadows, etc.), hydrology and soils characteristics, and clearly delineate these distinctions on a map. The final classification system, based primarily upon dominant vegetation cover, captures "natural" settings and common land-use practices in a specific and orderly fashion that accommodates USACE's plan formulation process. The "Middle Rio Grande Biological Survey" completed by Hink and Ohmart in 1984 described the plant communities within the study area's riparian zone and provided detailed information on species composition and the structure of cover types. Six general plant vegetation categories were developed by Hink and Ohmart (1984), based on the height of the vegetation and the makeup of the understory or lower layers:[2]

[1] Photo taken from abqstyle.com/albuquerque_photo/000023.html (May 2008).

[2] In actuality, the Hink and Omart classification requires field biologists to identify vegetation at the species level, and has generated a unique naming convention based on these characterizations. Those familiar with the Hink and Omart system should refer to *Appendix F* to see a crosswalk for cover types used in this assessment and the detailed Hink and Omart classification.

Type I: Mature Riparian Forests with tall trees ranging from 50 to 60 ft in height, closed canopies, and well established (relatively dense) understory composed of saplings and shrubs;

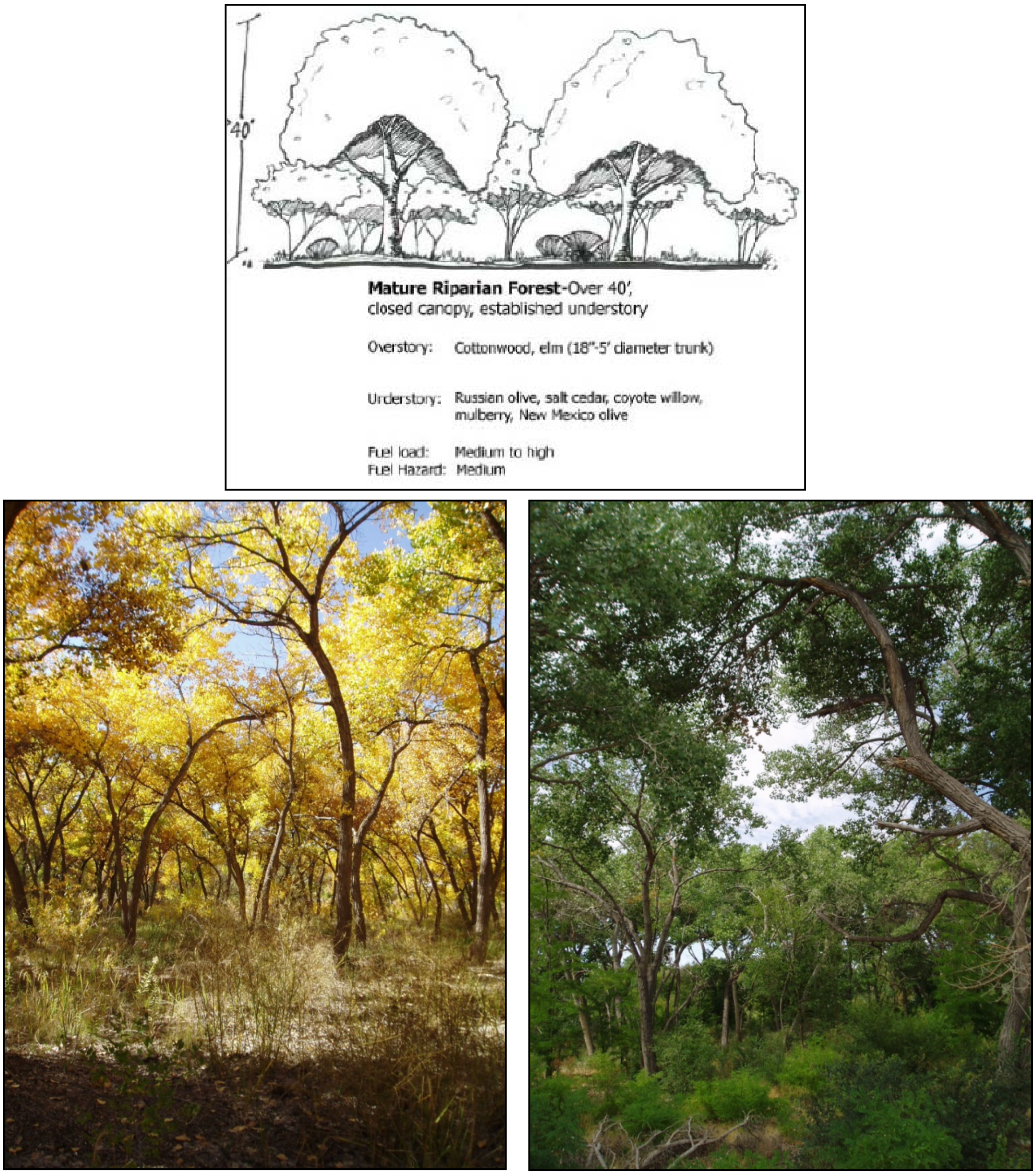


Figure 12. Classic examples of Type I (Mature Riparian Forests) vegetation in the study area.

Type II: Mature Riparian Forests with tall trees exceeding 40 ft in height and nearly closed canopies, but limited sapling and shrub understory;

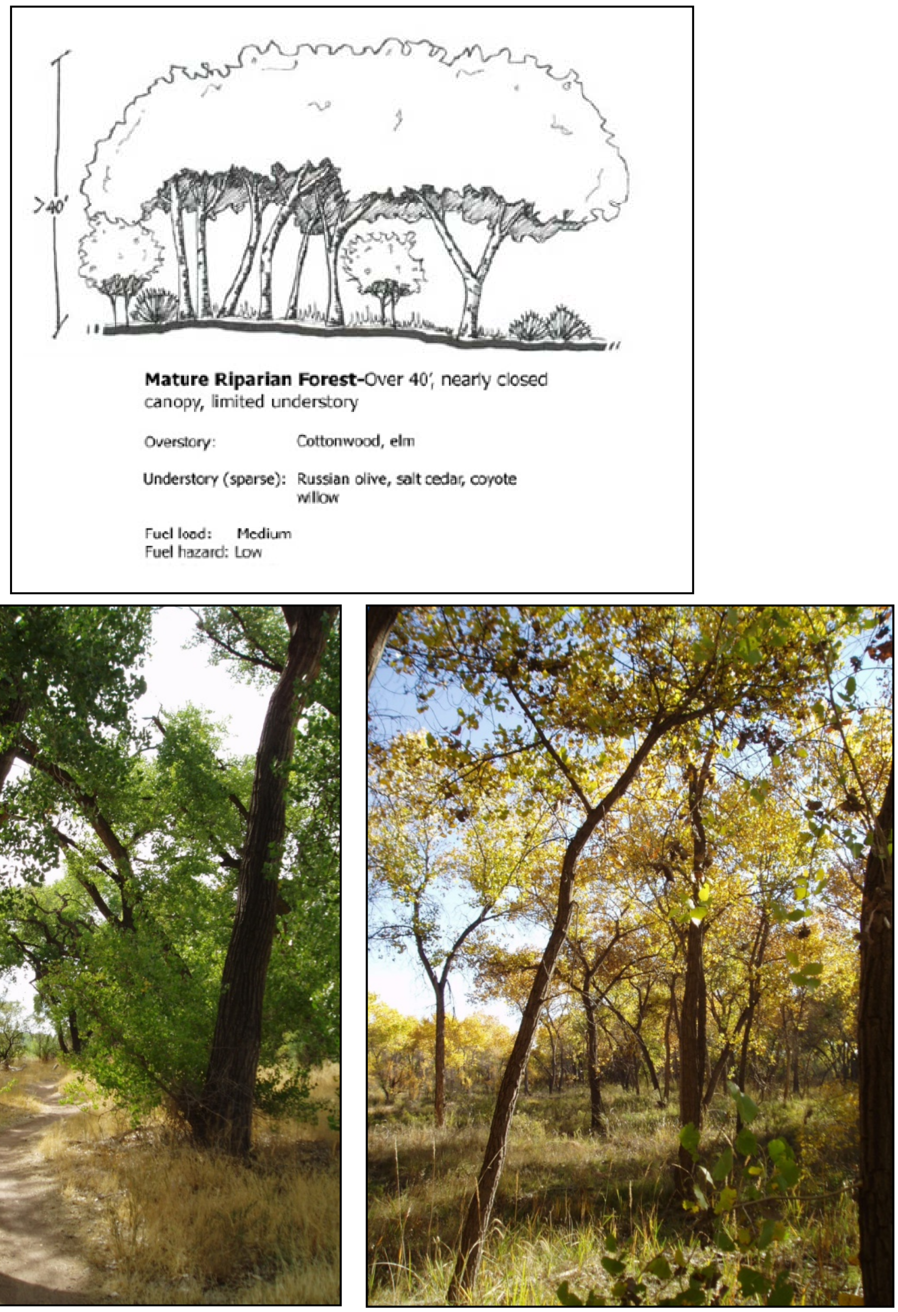


Figure 13. Classic examples of Type II (Mature Riparian Forests) vegetation in the study area.

Type III: Intermediate-aged Riparian Woodlands characterized by mid-sized trees less than 30 ft in height, but with closed canopies and dense understory;

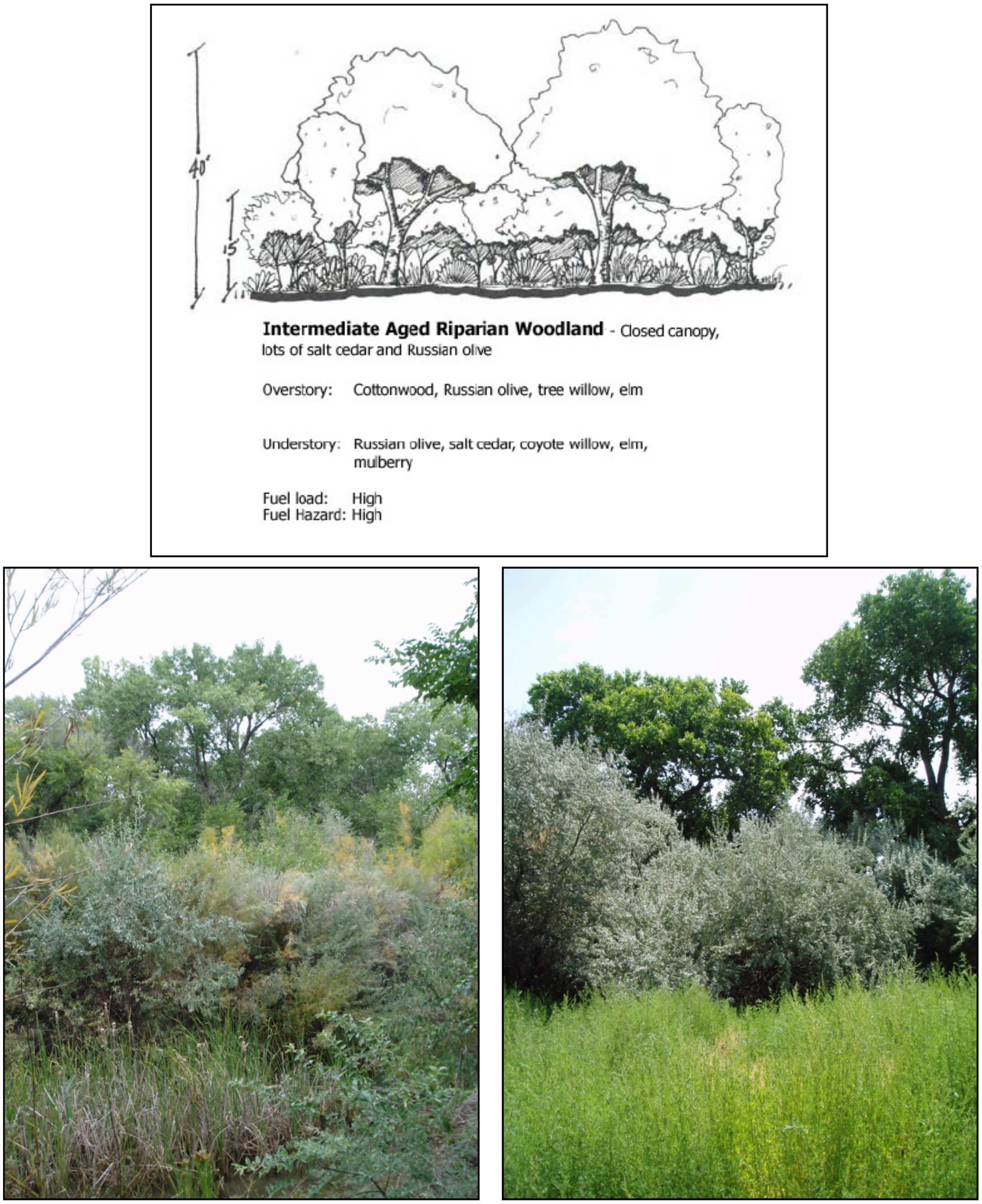


Figure 14. Classic examples of Type III (Intermediate-aged Riparian Woodlands) vegetation in the study area.

Type IV: Intermediate-aged Riparian Woodland/Savannahs characterized by open stands of mid-sized trees with widely scattered shrubs and sparse herbaceous growth underneath;

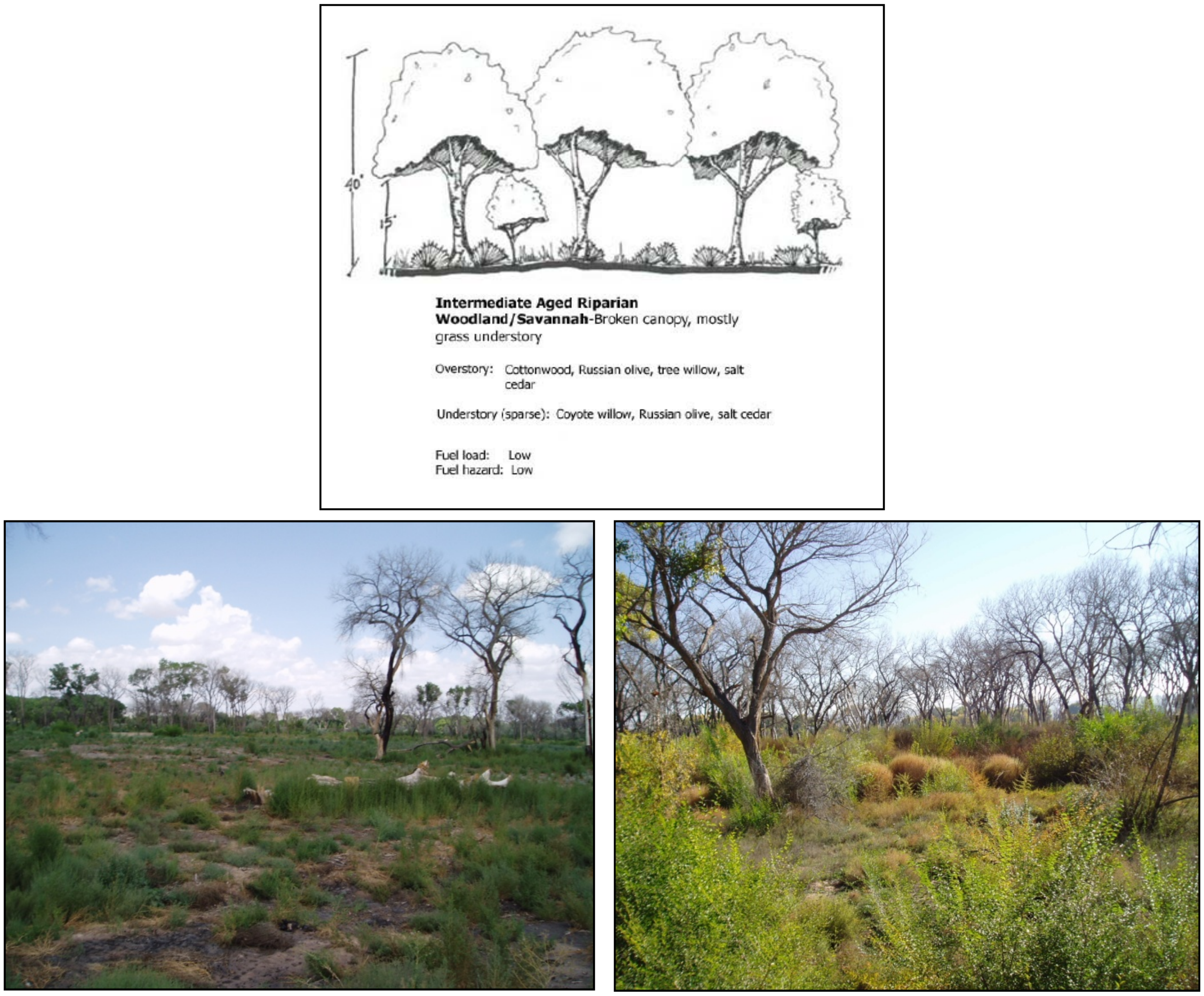


Figure 15. Classic examples of Type IV (Intermediate-aged Riparian Woodland/Savannahs) vegetation in the study area.

Type V: Riparian Shrubs are characterized by dense vegetation (shrubs and saplings) up to 15 ft in height, but lacking tall tree species, and often having dense herbaceous growth underneath; and

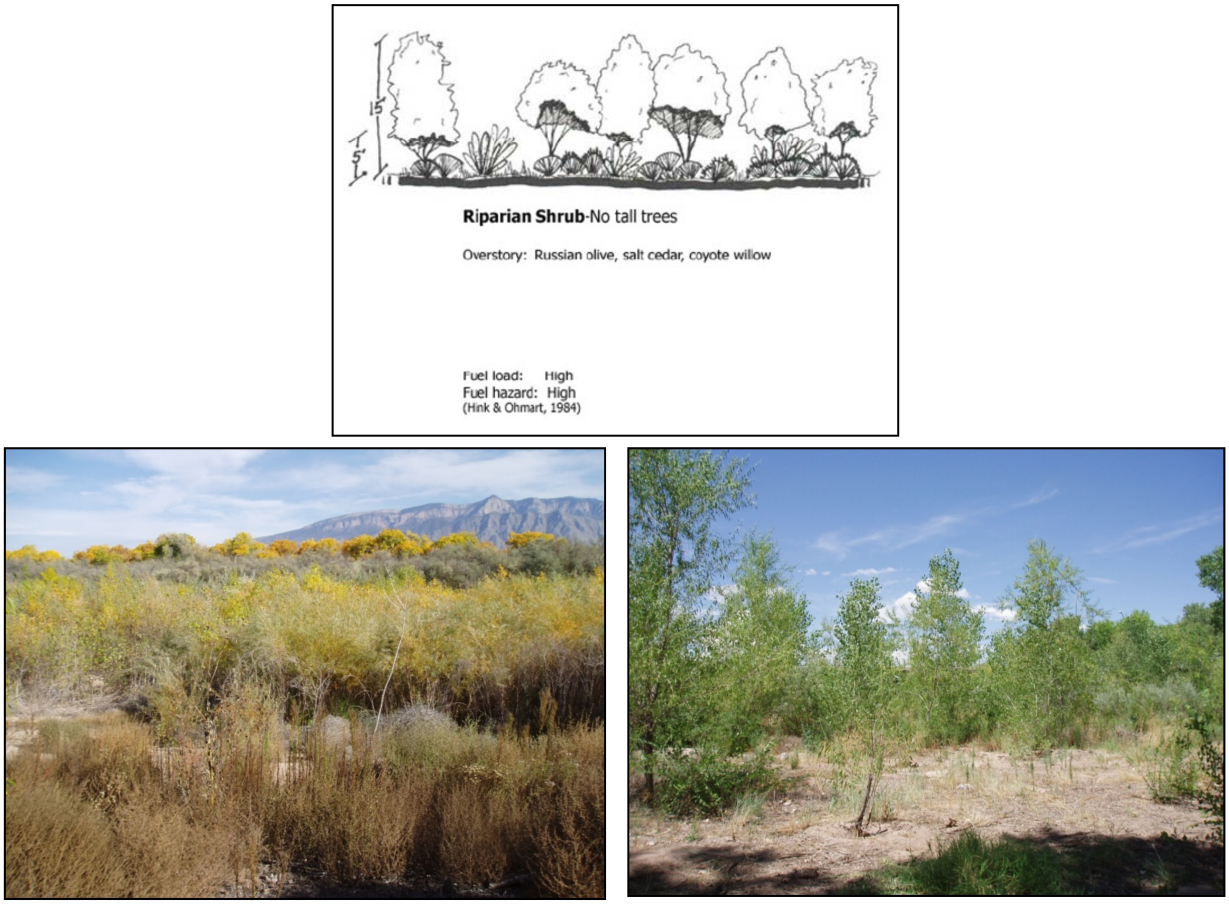


Figure 16. Classic examples of Type V (Riparian Shrubs) vegetation in the study area.

Type VI: Dry Grass Meadows and Wet Marshes are characterized by scattered plant growth composed of short shrubs (less than 5 ft in height), seedlings, and grasses. This category includes both dry meadows and the rare marshes found in the oxbow of the Rio Grande River that are vegetated with cattail, bullrush, sedges, watercress, and algae.

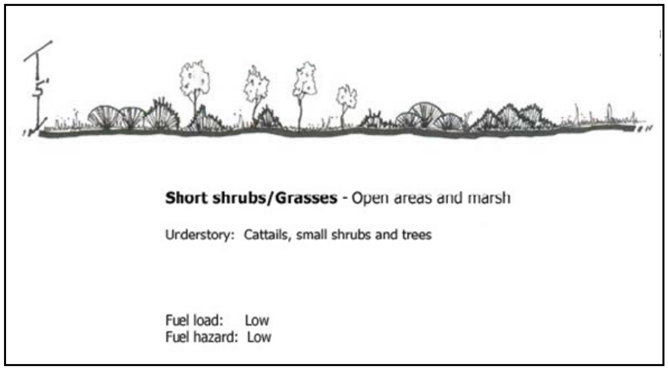


Figure 17. Classic examples of Type IV (Dry Grass Meadows and Wet Marshes) vegetation in the study area.

It should be noted that severe fires took place in June 2003, burning 253 acres (Figure 18), and as a result, the City of Albuquerque Open Space Division (AOSD) initiated an extensive thinning project to prevent future fires in the Albuquerque area.

Unfortunately, two more fires occurred in 2004 - one between Rio Bravo and Interstate-25 (I-25) on both sides of the river burning approximately 63 acres and the other south of Bridge Blvd. on the east side of the river, burning approximately 18 acres (USACE 2007b) (Figure 19).

Prior to these recent fires and between fires, the city has been thinning most areas within the Rio *Grande Valley State Park*. To date, approximately 2,300 of the 3,000 bosque acres in the park have been "treated" in some

Figure 18. Location of 2003 bosque fires (map taken from USACE 2007b).

Figure 19. The nighttime sky is aglow with the firelight coming off the bosque wildfires.

way by the AOSD, Ciudad Soil and Water Conservation District (SWCD), the Corps (through the Bosque Wildfire Project), and other agencies and private organizations. Some areas were lightly thinned while other areas were cleared of all non-native vegetation and dead material, depending on the level of fuel reduction required for the site. Clearing activities have greatly reduced the acreage of Type I, III, and V woodlands. Recently created Type II stands are largely devoid of understory vegetation. However, Russian olive and salt cedar have begun sprouting from the root crowns of cut trees in treated stands.

Because the "treated" habitats were significantly different in terms of vegetative cover, infiltration, etc., from the "untreated" cover types in the region, the E-Team made a decision to capture these differences by dividing several of the Hink and Ohmart categories (namely Types II, IV, and VI) into "Treated" and "Untreated" classifications (designated by "U's") to better capture the degraded habitat conditions in "fire-managed" areas within the study boundary (Figure 20). [1]

[1] Because the Albuquerque District knew that the fires and treatments had caused significant changes to the existing vegetation in the study area, an effort was undertaken to ground-truth and remap the reach in 2005 (again using the Hink and Ohmart (1984) methodology and classification scheme). Details of this effort are described in USACE 2007b. The 2005 updated mapping was used for this assessment.

Figure 20. Untreated forests (left) carry extensive fuel loads susceptible to catastrophic fires. The District and stakeholders actively reduce fuel loads to reduce the risk (right). These areas have reduced functionality (lower habitat suitability).

Open areas not associated with the model have been mapped, and offer potential areas of restoration and rehabilitation within the study area. To complete the characterization, a series of “Newly Developed” coverages were created as placeholders for conversion of the open areas and existing degraded areas into newly restored wetland (riparian) habitats. In the MRGBER study, 24 unique habitat types (i.e., cover types or CTs) were identified and mapped across the entire project study area (Table 2).

Table 2. Cover types identified and mapped for the MRGBER study area.

No.	Code	Cover Type (and Land Use) Description
1	TYPE_1	H&O Class I not treated - MATURE RIPARIAN FOREST (Over 40’ – closed canopy, established understory).
2	TYPE_2T	H&O Class II treated - MATURE RIPARIAN FOREST (Over 40’ – nearly closed canopy, limited understory).
3	TYPE_2U	H&O Class II not treated - MATURE RIPARIAN FOREST (Over 40’ – nearly closed canopy, limited understory).
4	TYPE_3	H&O Class III not treated - INTERMEDIATE AGED RIPARIAN WOODLAND (Closed canopy, lots of salt cedar and Russian olive).
5	TYPE_4T	H&O Class IV treated - INTERMEDIATE AGED RIPARIAN WOODLAND/SAVANNAH (Broken canopy, mostly grass understory).
6	TYPE_4U	H&O Class IV not treated - INTERMEDIATE AGED RIPARIAN WOODLAND/SAVANNAH (Broken canopy, mostly grass understory).
7	TYPE_5	H&O Class V Shrublands not treated - RIPARIAN SHRUB (no tall trees).

No.	Code	Cover Type (and Land Use) Description
8	TYPE_6T	H&O Class VI dry (grass) meadow treated - SHORT SHRUBS/GRASSES – Open areas.
9	TYPE_6U	H&O Class VI dry (grass) meadow not treated - SHORT SHRUBS/GRASSES – Open areas.
10	TYPE_6W	H&O Class VI wet meadow not treated - SHORT SHRUBS/GRASSES – Open areas and Marsh.
11	OPENLAND	Open Areas
12	OPENWATER	Open Water
13	NEWTYPE_1	Newly Developed Type 1
14	NEWTYPE_2T	Newly Developed Type 2T
15	NEWTYPE_2U	Newly Developed Type 2U
16	NEWTYPE_3	Newly Developed Type 3
17	NEWTYPE_4T	Newly Developed Type 4T
18	NEWTYPE_4U	Newly Developed Type 4U
19	NEWTYPE_5	Newly Developed Type 5
20	NEWTYPE_6T	Newly Developed Type 6T
21	NEWTYPE_6U	Newly Developed Type 6U
22	NEWTYPE_6W	Newly Developed Type 6W
23	ISLANDS	Islands
24	UTILITY	Utility Areas

Cover types identified as "NEW" refer to newly developed areas proposed in conjunction with construction of proposed alternatives.

The existing cover types were subsequently mapped using a Geographic Information System (GIS) and ground-truthed during the 2005 field season (Figure 21).

Of the 5, 321 acres mapped within the project boundary, the majority of the habitat was characterized as either Type I (Mature Riparian Forest – 2,111 acres) or Open Water (1,526 acres) (Figure 22).

The remaining Hink and Ohmart categories, namely Types II-VI, were relatively evenly represented (4-11%, 1,384 acres collectively), with the remaining acreages tied up in utility areas and open areas (253 acres or 4.4%).

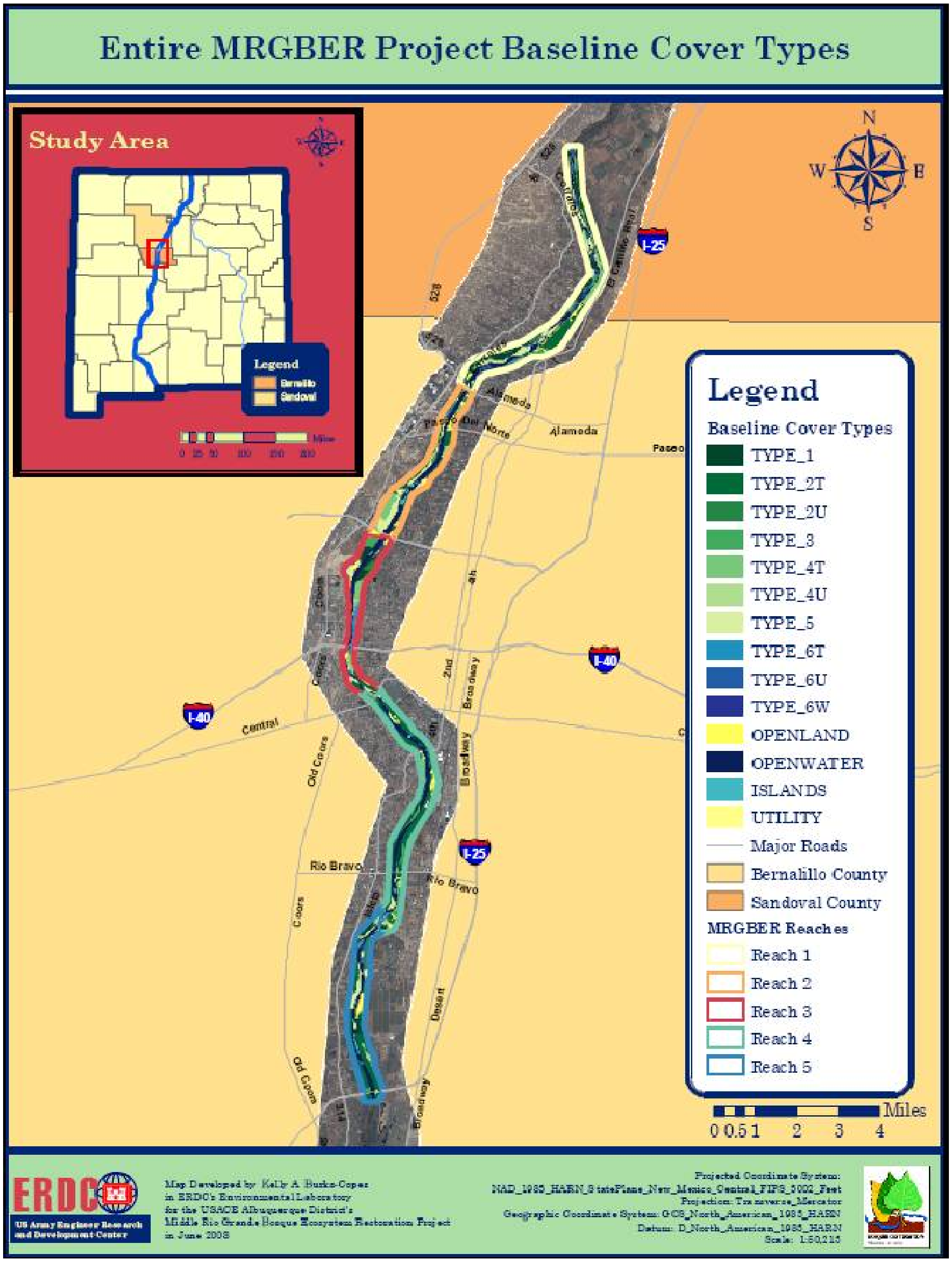


Figure 21. Baseline cover type map for the project study area. [1]

[1]GIS shapefiles are available upon request - contact the District POC (Ondrea Hummel, contact information can be found in *Appendix D*).

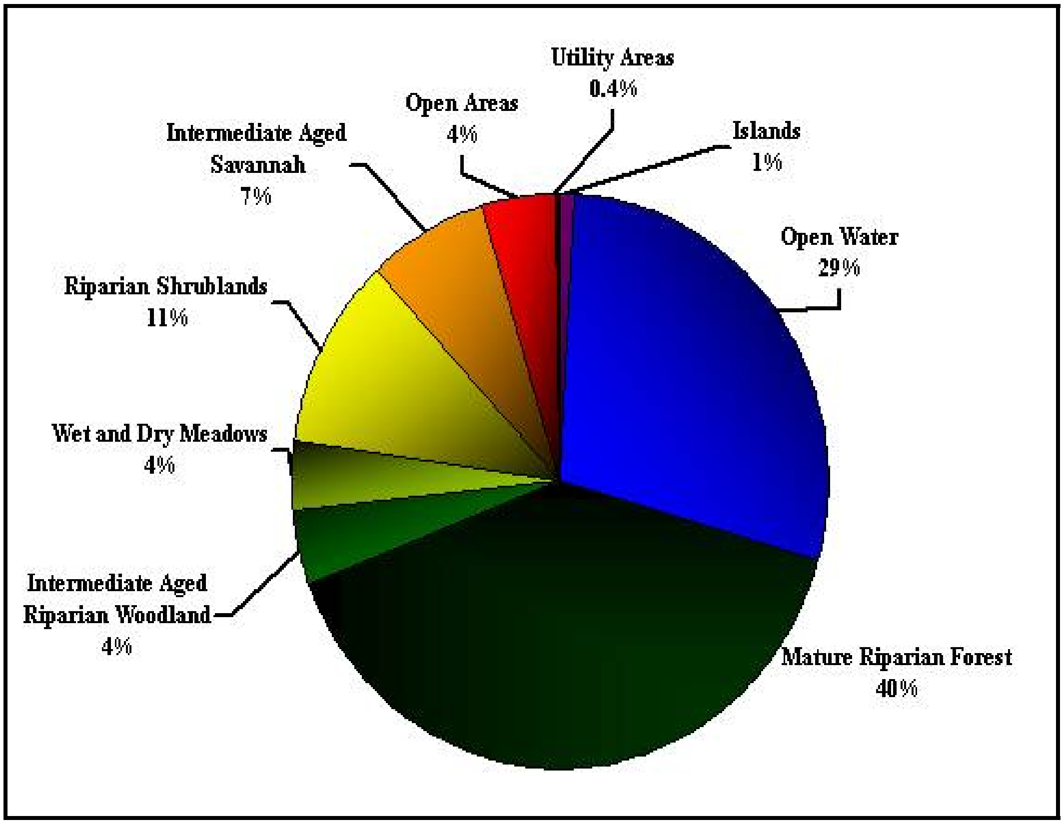


Figure 22. Acreage distribution of cover types in the MRGBER study area.

Hydrologic characterization

Riparian wetlands develop and are maintained through time as the hydrologic cycle interacts with the landscape (Figure 23).

These ecosystems then are the local manifestation of broader, large-scale processes (Bedford 1996). They occur in particular hydrogeological settings where characteristics of the landscape and climate favor the accumulation or retention of surface water and/or soil water (Winter 1988, Winter and Llamas 1993). Hydrogeologic setting refers here to the position of the bosque in the landscape with respect to the flows of surface water, groundwater, and the geological characteristics that control the flow of water. These geological characteristics include surface relief, land surface slope, thickness and permeability of soils, and the composition, stratigraphy, and hydraulic properties of the underlying geological materials (Bedford 1996). Together, climate and the hydrogeologic setting determine the key variables that lead to the development and maintenance of the bosque community. Depending on the climatic setting and hydrogeologic position in the landscape, riparian wetlands receive varying proportions of their water supply from precipitation, groundwater, and surface flooding.

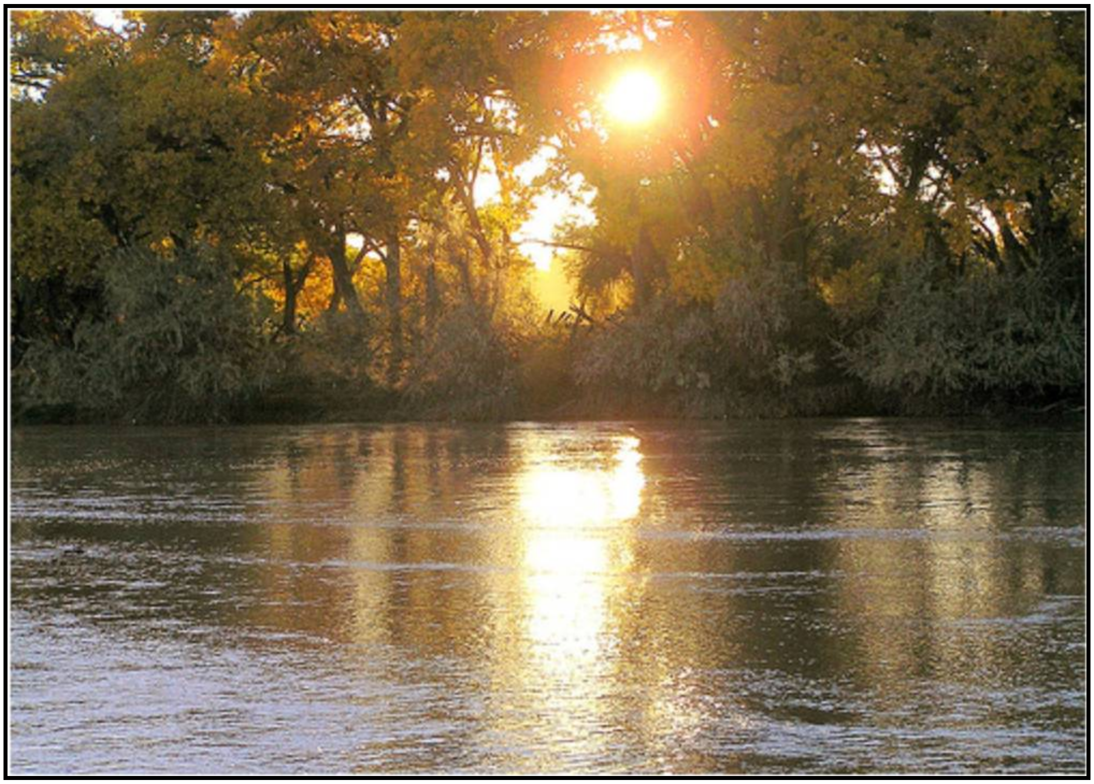
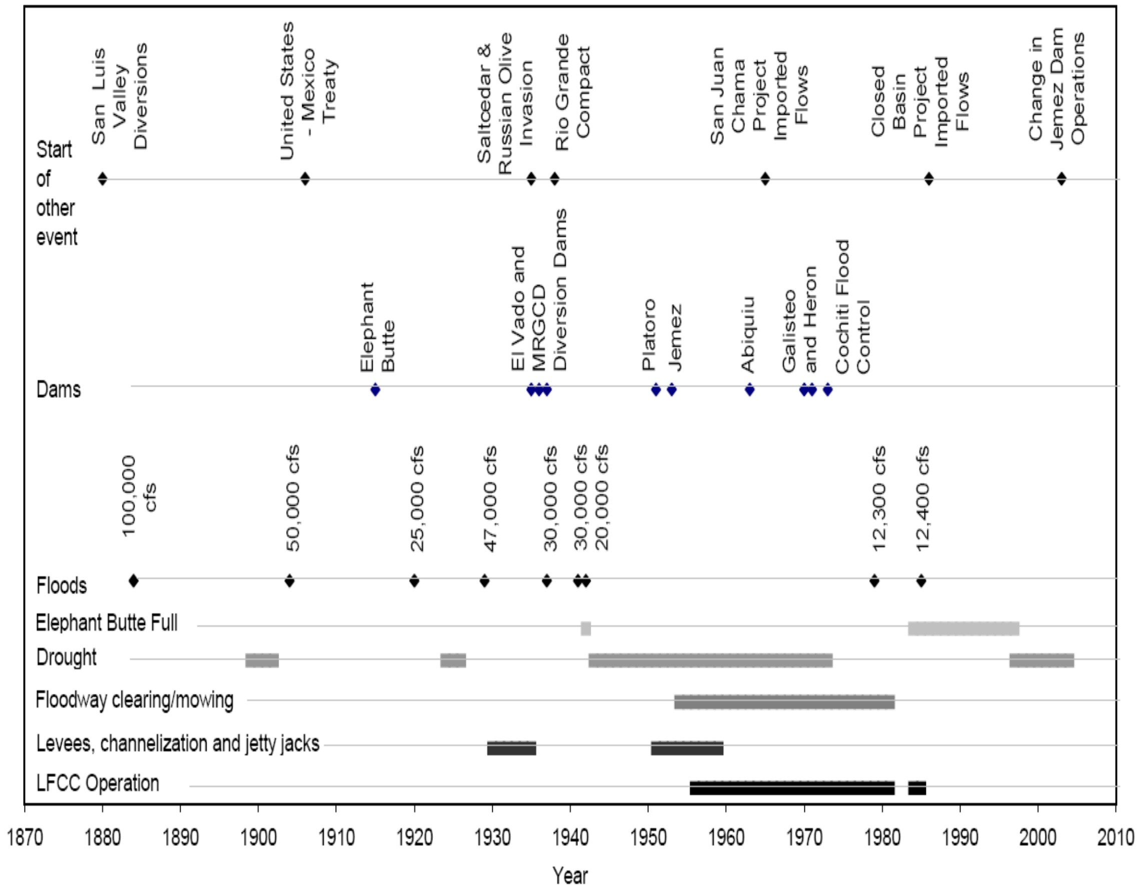


Figure 23. The hydrologic connection to the bosque is readily apparent. The diversity and health of the riparian community hinges on the restoration of natural flood pulsing to facilitate sediment deposition and subsequent cottonwood recruitment.[1]

Natural flows in the Rio Grande system are derived from two primary sources: (1) snowmelt originating predominately from the upstream, higher elevation portions of the watershed, and (2) summer thunderstorms that tend to be more localized and concentrated at lower elevations (USACE 2007a). Under natural, unconstrained river conditions, the annual flow volume varies significantly from year to year, depending on climatic conditions (Waltemeyer 1987). Annual variations in the timing and volume of streamflow in the Rio Grande are strongly influenced by the El Niño-southern oscillation through its modulation of the seasonal cycles of temperature and precipitation and their effects on snow accumulation and melting (Lee et al. 2004). These cycles can be several years to decades long and can result in extended drought or wet periods. An extended period of below-average precipitation occurred from the early 1940s through the mid-1970s and above-average precipitation from 1981 through the mid-1990s (National Oceanic and Atmospheric Administration [NOAA] 2002). The annual flood regime varies significantly from year to year due to this natural variability in climate and precipitation.

[1] Image from http://flickr.com/photos/58969260@N00/1972259609/ (September 2008).

Human activities affecting flows in the Rio Grande system have been documented back to the arrival of Spanish settlers in the late 16th century (Wozniak 1997). Significant changes in the Rio Grande occurred during the past century in response to a combination of human-induced factors (Figure 24).



Notes: cfs = cubic feet per second; LFCC = Low Flow Conveyance Channel; MRGCD = Middle Rio Grande Conservancy District

Figure 24. Timeline of human activities since 1880 that have affected the Rio Grande (USACE 2007a).

These alterations to the environment equate to significant changes in land use through time and space. Construction of reservoirs, changes to and expansion of historic irrigation conveyance systems, upland drainage networks, and bank stabilization have all served to modify the flow regime of the Rio Grande and associated groundwater recharge dynamics (Hansen and Gorbach 1997, Scurlock 1998, Wozniak 1997). Many of these alterations have resulted in the general tendency for extending runoff hydrographs, reducing peak-flow runoff events, limiting dry-channel vegetative colonization (i.e., new channel formation), and limiting lateral channel

migration; resulting in a persistent and additive transition away from a more natural disturbance regime (USACE 2007a). These characteristics now dominate the nature and behavior of the Rio Grande. The eight major dams listed in Figure 24 affect flows in the river by storing and releasing water in a manner that generally decreases the flood peaks and alters the timing of the annual hydrograph, but they do not necessarily cause significant changes in the annual flow volume.

The hydrologic characteristics of the Middle Rio Grande Reach have been characterized primarily based on flow records collected during the past century (USACE 2002, 2003a, 2007b, Burks-Copes and Webb 2009). These records provide a means of quantifying the most significant changes that occurred as a result of upstream flow regulation and storage, imported flows, cycles of drought and above-average precipitation, and changes in land use. The following natural and human-caused hydrologic characteristics are particularly important to the existing geomorphology of the reach:

- Flows during the spring snowmelt season in April, May, and June typically make up more than half of the total annual runoff in the system. On an average annual basis, the total runoff volume was higher during the past four decades than it was in the earlier recorded period due to a combination of imported flows and higher than average precipitation during portions of that period (USACE 2007a).
- Flows associated with frequently occurring floods in the 1.5- to 10-year range are generally believed to have the most significant influence on channel form (Wolman and Gerson 1978). The morphologic characteristics of rivers in arid environments such as the Rio Grande are also strongly affected by larger, less frequent floods that create a disturbance regime that effectively “resets the clock” by altering the characteristics that develop during the intervening lower flow periods (Graf 1988). In spite of the increase in total runoff, both the average annual maximum mean daily flow (which is used to represent the mean annual flood peak) and the infrequent, large magnitude peak discharges have decreased in all reaches downstream from Cochiti Dam, presumably due to the presence of upstream dams (USACE 2007a).

The river and adjacent environs respond to cycles of drought and above-average precipitation that occur over periods of several years through a variety of mechanisms, including changes in riparian vegetation, channel

narrowing during drought periods, and channel widening through bank erosion and migration during wet periods. Generally, these processes vary widely over both time and space and represent a fundamental organizing force throughout the river system. Over the passage of time, different flow regimes (both high and low) have shaped the riparian plant community by means of deposition and scour; however, widespread and large-scale human alterations in the last century have muted this pattern and disrupted the natural disturbance regime (Crawford et al. 1993, Hansen and Gorbach 1997, Scurlock 1998, Wozniak 1997).

Geomorphic characterization

River systems are often described as being in a state of dynamic equilibrium. The equilibrium actually results from a series of processes that are predicated on change. Even when large-scale hydrological factors are essentially constant over a short period of time, changes can be happening in subareas as small as the outside bank of a meander or as large as many river miles upstream or downstream from a tributary inflow. Likewise, this state of dynamic equilibrium can withstand climatic deviations from the norm that persist for periods ranging from several decades to one-day flood events (Crawford et al. 1993). Leopold et al. (1964) noted that the geomorphic processes triggered in response to a change in the magnitude or duration of a variable, either naturally caused or human-induced, will be the same. A river system is constantly adjusting, trying to achieve a new equilibrium between its discharge and sediment load (Bullard and Wells 1992).

Historically, the Rio Grande River in this region was a heavily braided, aggrading stream meandering freely across a wide floodplain much larger than the current floodway ecosystem. As it meandered through time and space, the river created and renewed a mosaic of riparian communities from cottonwood riparian gallery forest and coyote willow shrublands, to wet meadows, oxbow ponds, and open-water areas (Figure 25).

As a result of several channelization projects (installation of levees and jetty jacks) the river has become constrained to a single, narrow floodway throughout much of the Middle Rio Grande, resulting in an approximately 85-% loss of the original floodplain (Earth Reflections 2003). Figure 26 shows the approximate location of the historic 500-year floodplain in Albuquerque. The current floodplain is generally confined within the levees, which are also shown on the figure. Historically it was bounded by lower

terraces, then by 300- to 500-ft-high mesas. The mesas slope gently upward to the foot of the mountain ranges (predominantly to the east) or to plateau highlands (predominately to the west).

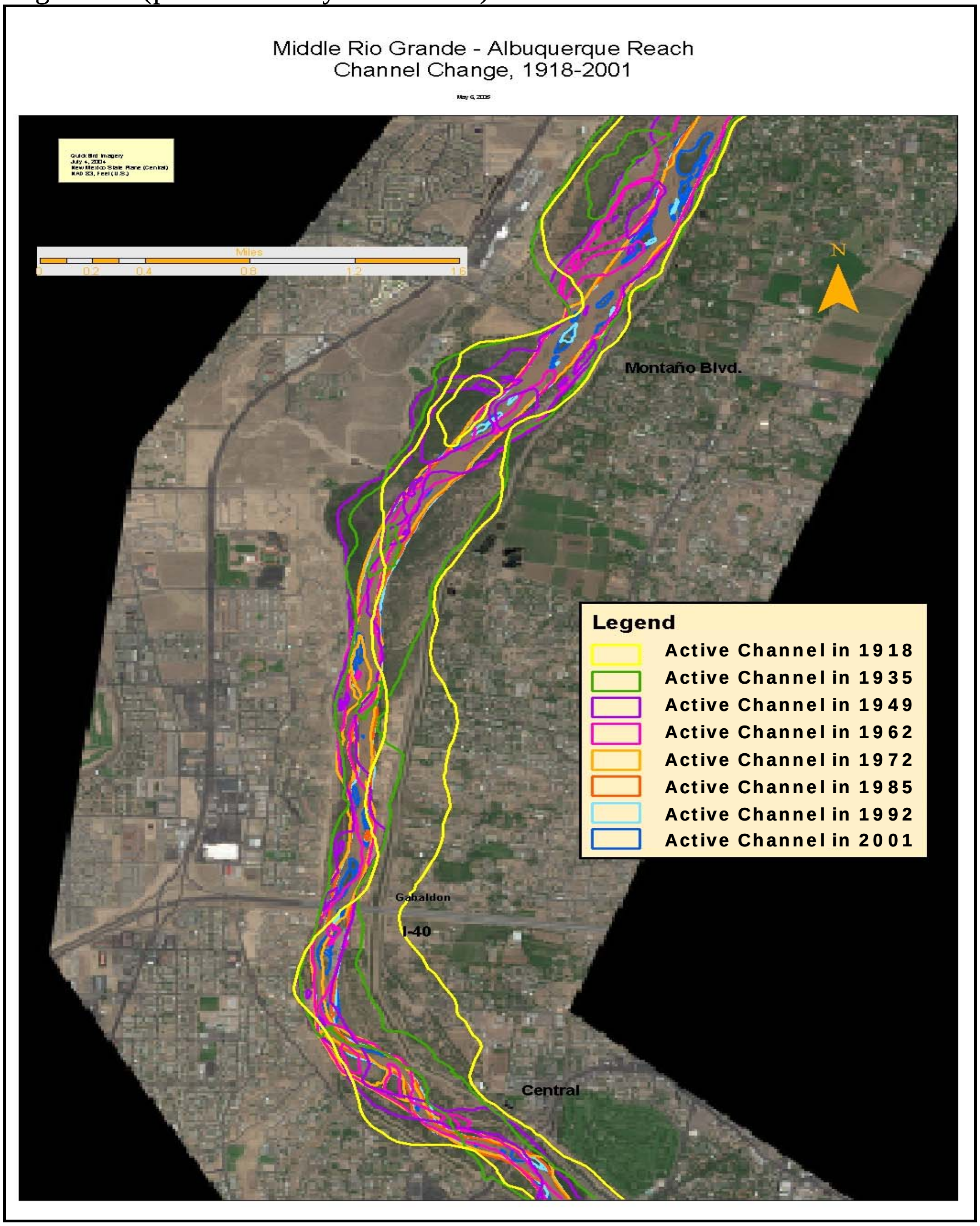


Figure 25. The Rio Grande River was once a heavily braided stream meandering across the arid area.

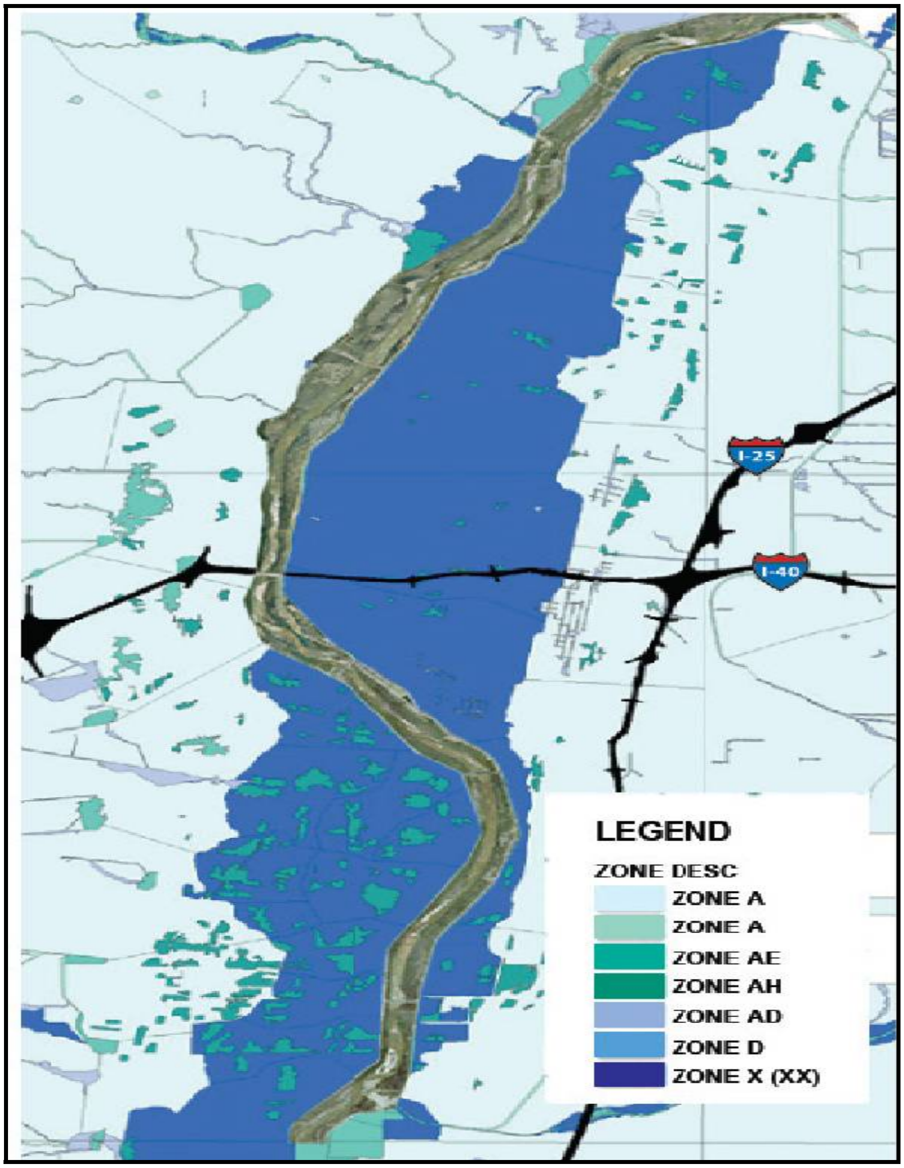


Figure 26. The historic 500-year floodplain of the Middle Rio Grande was once much wider than its current channelized state.

Past flood control and drainage projects implemented were widely successful in rejuvenating the declining agricultural communities and providing opportunities for expanding settlements. This occurred, however, at the expense of wetlands and marshes, which were dramatically reduced in number and extent (Berry and Lewis 1997, Crawford et al. 1996, Leopold et al. 1964, Hanson 1997). Although there are several small areas and former side channels in the area that function as seasonal wetlands, there are no longer any wetlands of significant size in the region.

Changes in seasonal discharge patterns have strongly impacted channel-forming processes. Discharge is the dominant variable that affects channel morphology, but sediment transport, channel bed and bank material, and other hydraulic factors are also important influences. Historically, the wide shallow channel was described as a sand-bed stream (Nordin and Beverage 1965) with a braided pattern likely resulting from sediment overload (Woodson 1961). The river followed a pattern of scouring and filling during floods and was in an aggrading regime (accumulating sediment). Flood hazards associated with the aggrading riverbed prompted the building of levees along the floodway. However, the levee systems have confined the sediment and increased the rate of aggradation in the floodway. Additionally, channel stabilization activities which included the installation of jetty jacks during the 1950s and 1960s contributed to building up and stabilizing the over-bank areas in the existing bosque (Figure 27).

Figure 27. Jetty jacks lined along the bank of the Rio Grande trap sediment and plant material during flooding events, and have stabilized over-bank areas over the course of several years.

Construction of dams at Jemez Canyon (1953), Abiquiu (1963), Galisteo Creek (1970), and Cochiti (1973) was expected to slow aggradation or reverse the trend and promote degradation in the Middle Rio Grande Valley. The flood control improvements have reduced the sediment load in the Middle Rio Grande and accomplished flood control objectives for much of the river valley. This has caused changes in the geomorphology of the Rio

Grande through the Albuquerque reach and affected the conveyance capacity of the active river channel. The result of these changes has been a reduction in the frequency of over-bank flows into the Rio Grande Bosque.

Currently within the area, the Rio Grande is predominantly a sand bed river with low, sandy banks. There are numerous sandbars, and the river channel tends to be straight due to jetty jack fields and levee placement (Crawford et al. 1993) (Figure 28).

Figure 28. The middle Rio Grande is often characterized by numerous sandbars and a straight channel resulting from the placement of jetty jack fields and levees.

In this area, the river is typified by a uniform channel width averaging approximately 600 ft. Approximately 2 ft of degradation has occurred in the Albuquerque reach (due to flood control measures upstream) with no significant change in bed material (Mussetter Engineering, Inc. 2006). The slope of the riverbed is less than 0.01 ft/ft (Tashjian 1999). At flows less than the bankfull, the river is establishing a sinuous configuration within the cleared floodway.

Habitat Suitability Index (HSI) model

The mix of water sources, and the geologic materials through which they move before reaching the riparian zone, combine to determine the elemental composition, nutrient status, and biodiversity of the unique bosque community (Figure 29).

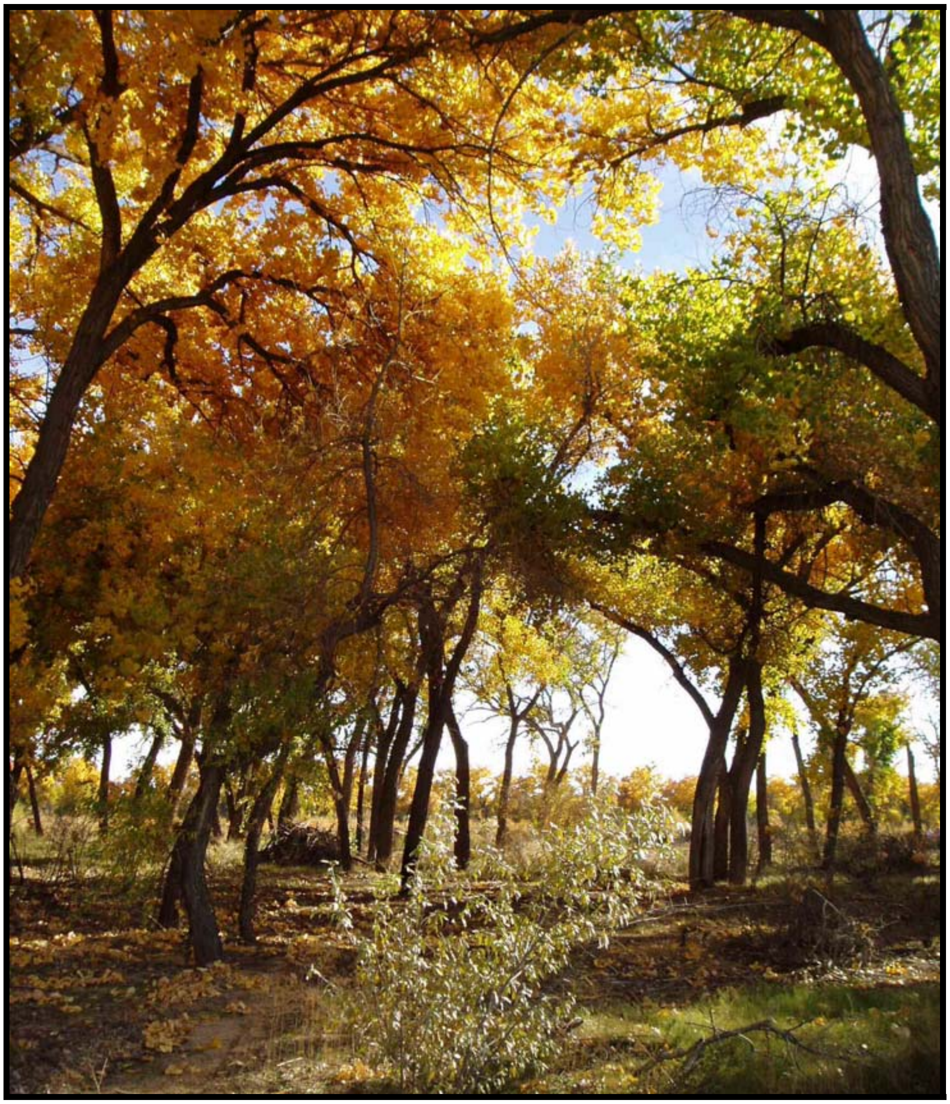


Figure 29. The challenge for the E-Team was to develop a model robust enough to capture the unique character of the Middle Rio Grande's bosque community.

The amount of groundwater inflow relative to precipitation, and geologic materials through which the groundwater flows, dictate the biogeochemistry of the bosque community. And finally, the nature and spatio-temporal dynamics of water within the bosques and between the bosque and adjacent ecosystems dictate the functionality and integrity of these unique systems. In particular, the movement of water within the bosque, the flows of water between the bosque and adjacent systems, and the consequent exchange of materials (e.g., sediments, nutrients, propagules) that occur within the bosque and the adjacent systems literally shape these unique ecosystems.

Model components

For the Bosque Riparian Community HSI Model, three model components (i.e., Hydrology; Structure/Soils/Biotic Integrity; and Spatial Integrity/ Disturbance) were identified as the key functional indicators necessary to model the integrity of this unique community. The following sections describe the underlying principles governing the selection of these critical functional components and provide a customized flow-diagram to indicate how they were combined to develop a HEP-compatible index model for the ecosystem restoration application.

Functional component #1: Hydrology (RIP-HYDRO)

Water operations at the various facilities on the Rio Grande affect the surface and groundwater available to the riparian ecosystem. Periodic overbank flooding is necessary to the health of established native plant communities and literally "…creates the distribution of different communities and age classes" (Scurlock 1998). Regulated flood flows may prevent the overbank floods necessary to scour away existing vegetation and make new seedbeds for cottonwoods and other native trees (Scurlock 1998). Riparian areas that seldom receive overbank flooding show a definite lack of both structural and species diversity. Canopy trees tend to be mature, same-aged stands that are not regenerating. The understory becomes littered with deadfall, a fuel load that inhibits growth of desirable grasses, forbs, and other understory species (Figure 30).

Restricted flow regimes changed the nature of riparian areas in the Rio Grande, adversely affecting cottonwood and other native plants. Many areas of the Rio Grande floodplain, both inside and outside the levees, contain relic stands of mature cottonwood and willow that have not flooded for several decades. Riparian vegetation that is not regularly flooded is more vulnerable to encroachment by non-native salt cedar and is extremely vulnerable to fire because of the accumulation of debris that occurs with reduced peak flow events (Ellis et al. 1996). The timing, duration, and magnitude of peak flows are critical to habitat creation and maintenance. Peak flow variability contributes to the diversity of vegetation and wildlife. Seasonally flooded riparian zones exhibit both structural and species diversity in the canopy and understory. Banks are scoured and reshaped, forming depressions that support vital wetland areas and associated species.

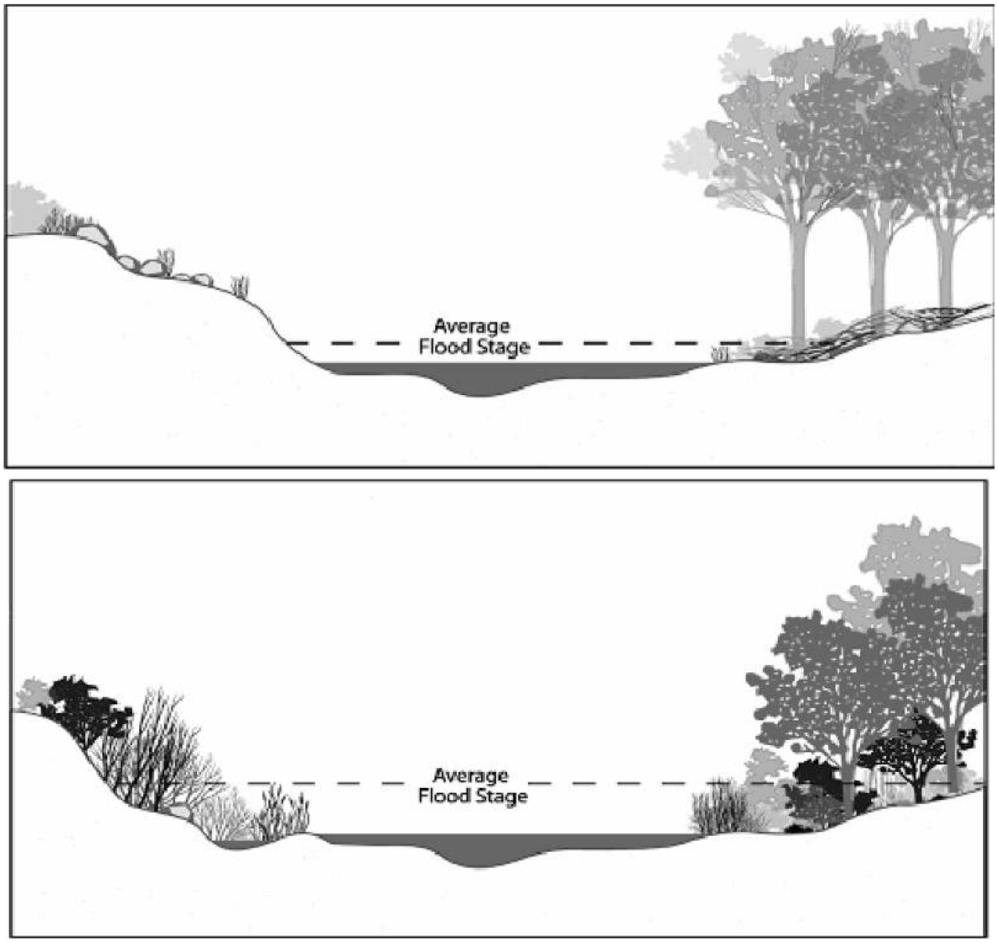


Figure 30. Vegetation response to no overbank flooding (above) versus regular flooding in the riparian zone (below) (USACE 2007a).

Thus, the physical characteristics of natural rivers and their associated bosque riparian communities are strongly controlled by the magnitude, duration, and timing of the natural, unconstrained flows that pass through them (Schumm 1977). The natural flows are in turn controlled by the climatic, geologic, and physical characteristics of the contributing watershed (Lee et al. 2004). These natural physical characteristics can be significantly altered by human activities that change infiltration and runoff patterns; that store and release water in ways that alter the natural runoff cycle and change the sediment supply; and that constrain the river to protect adjacent property from flooding and erosion (USACE 2007a). In terms of the bosque's HSI model, indicators of hydrologic function include depth to groundwater, flooding frequency and duration, as well as ratios of wetted area for depressional wetlands. The existing form of the Rio Grande's bosque community results from a combination of these factors (Figure 31).

Figure 31. Hydrology dictates the functionality of the bosque ecosystem.

Functional component #2 Structure/Soils/Biotic Integrity (RIP - BIOINTEG)

Today, the bosque is comprised of a dynamic mosaic of cottonwood forests, coyote willow shrublands, wet meadows, wetlands, oxbow ponds, and open-water areas with a variety of depths and flows. These wetlands and riparian forests rely entirely upon periodic flooding events to regenerate soils and create new substrates for vegetative colonization. Unlike many upland areas, the primary natural disturbance regime at work in the Rio Grande ecosystem is flooding. As a patchwork of wetlands, open water, wet meadows and woodlands, these riparian areas provide habitat to a greater number of wildlife species than any other ecological community in the region and serve as a critical travel corridor for many species, especially migratory birds moving with the change of seasons.

Although these riparian ecosystems are considered to be the most productive and biologically diverse ecosystems in the region, they are now believed to be the most threatened (Johnson and Jones 1977, Johnson et al. 1985, Knopf et al.1988, Ohmart et al. 1988, Johnson 1991, Minckley and Brown 1994). Substantial impacts from human activities, starting about 250 years ago, have resulted in compounding rates of change in structure and vegetation dynamics to the point that the bosque ecosystem is now on the verge of irreversible conversion (Crawford et al. 1996) (Figure 32).

Figure 32. Along the banks of the Middle Rio Grande, anthropogenic pressures have resulted in an extremely degraded bosque community subject to catastrophic fires, exotic species encroachment, and a loss of vegetative recruitment in the cottonwood riparian community. In 50 years, the bosque could be completely devoid of riparian forest without intervention.

In ecological terms, the cumulative effects of these activities have resulted in a disruption of the original hydrologic (hydraulic) regime. This overbank flooding regime is key to the decomposition of leaf litter and dead wood, which are both fire hazards and obstacles to riparian forest regeneration. With the onset of these periodic flooding events, dissolved salts are flushed from the system, nutrients are cycled into the ecosystem, and soils are renewed. Without flooding, and with the increased demand on water resources in the region, the riverbanks have destabilized and are now "perched" above the river itself (Figure 33).

Structural changes in the riparian vegetation were rapid and easily detected. For example, the valley lost over half its wetlands in just 50 years (Crawford et al. 1993). Similarly, cottonwood germination, which requires scoured sandbars and moisture provided by high river flows (Stromberg et al. 1991, Scott et al. 1993) has decreased, resulting in limited establishment of new trees and a predicted decline in the regional population (Howe and Knopf 1991).

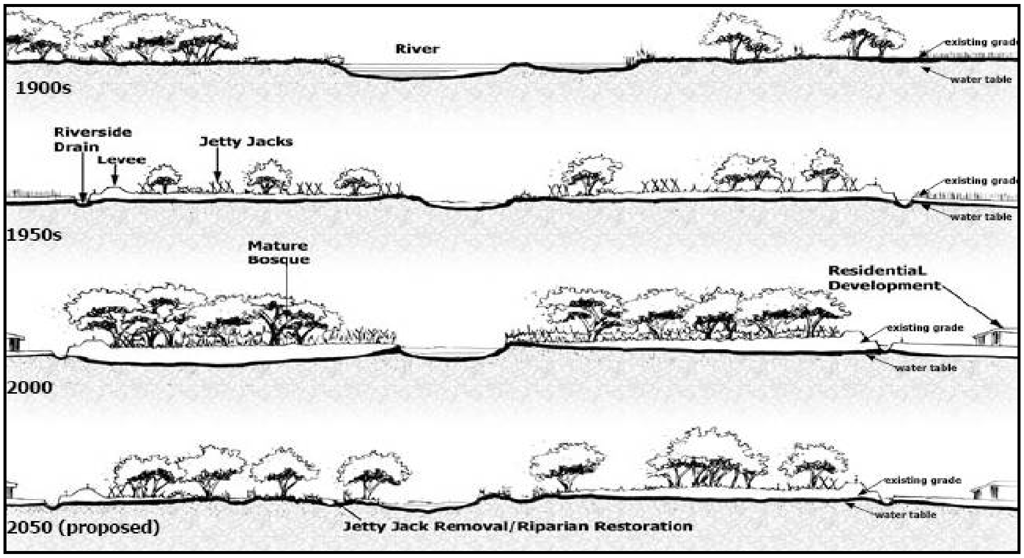


Figure 33. Flood protection projects (e.g., levees, riverside drains, and jetty jacks) have reduced the Rio Grande's original floodplain to a fraction of its size in the study area (USACE 2003a).

Ultimately these conditions have favored the encroachment of exotic species. Salt cedar (*Tamarix ramosissima*), Siberian elm (*Ulmus pumila*), Russian olive (*Elaeagnus angustifolia* L.), tree-of-heaven (*Ailanthus altissima*), and Bermuda grass (*Cynodon dactylon*) have colonized large portions of the bosque, outcompeting and replacing the native species. These exotics do not rely upon the spring flooding regime to reproduce, consume more water than the natives, compound the fire hazards in the area, and fail to provide critical habitat for many key wildlife species. Without significant restoration and changes in the current water management, these exotics may dominate riparian forests within the next 50 to 100 years (Howe and Knopf 1991).

In terms of the bosque's HSI model, the vegetative species compositions of living plant biomass within the bosque dictate the ecological integrity of the ecosystems and suggest whether the systems can support animal populations and guilds. The emphasis of the HSI model was therefore placed upon the dynamics of the plant community as revealed by the vegetative diversity (presence of natives and indicator species) and community structure of the habitats (Figure 34).

Healthy bosque ecosystems possess a natural complexity of physical features that provide a greater variety of niches and more intricate interactions among species. Local structural complexity increases with increased canopy cover, tree densities, vegetative layering, and

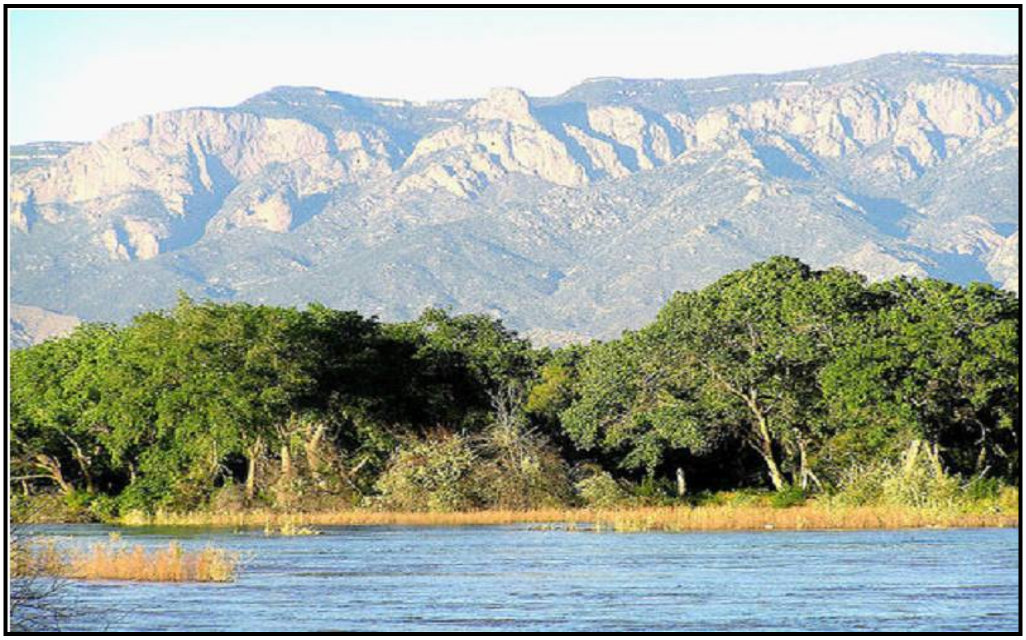


Figure 34. Vegetative indicators, particularly cover, densities, native species dominance and biodiversity, capture the bosque community's habitat potential.

accumulation of organic matter. The vegetation's physical characteristics and structures within the system dictate the habitat suitability of a system to support animal populations and guilds as well. The emphasis of the model is to capture the system's ability to provide physical space for its numerous terrestrial and aquatic inhabitants to meet key life requisite requirements (breeding, feeding and cover) (Figure 35).

Functional component #3: Spatial Integrity and Disturbance (RIP-SPATIAL)

At the landscape level, the bosque has a characteristic pattern and connectivity of habitat patches (Figure 36). The number of and the juxtaposition of these patches support the movement of species and the transfer of materials (energy and nutrients) among habitats [U.S. Environmental Protection Agency (USEPA) 1999]. The relevance of landscape structure to biodiversity is now well accepted, thanks to the voluminous literature on habitat fragmentation (Noss 1990 and numerous references therein). Landscape features such as patch size, heterogeneity, and connectivity within the riparian zone can be major controllers of species composition and abundance, and of population viability for sensitive species (Noss and Harris 1986). Furthermore, landscape pattern has been shown to strongly influence ecological processes and characteristics (McGarigal and Marks 1995). Turner (1989) describes how spatial structure influences most fundamental ecological processes, and how landscape planning and management, in turn, influence landscape structure.

Figure 35. Structural complexity offers numerous benefits to resident wildlife in the bosque community.

Figure 36. The San Antonio Oxbow offers an ideal perspective from above illustrating the classic bosque mosaic of unique patches of forested habitat ribboned throughout with wetland (meadow and marsh) complexes.

To adequately characterize the bosque's ecosystem functions, the system's "place" in the landscape must be captured along with the processes that "shape" the system (i.e., key corridors and habitat fragmentation) (Figure 37).

Figure 37. Fragmentation and urban encroachment are common problems for the bosque ecosystem.

Therefore, landscape-level characteristics (i.e., patch size and nearest neighbors as well as the levels of disturbance immediately adjacent to the system) were thought to dictate whether flora and fauna would find the bosque ecosystem serviceable. In general, high levels of disturbance were thought to perturb sensitive species and reduce the system's ecological integrity.

Model flow diagram

A flow diagram best illustrates the final model's design arising from the workshop and application efforts (Figure 38).

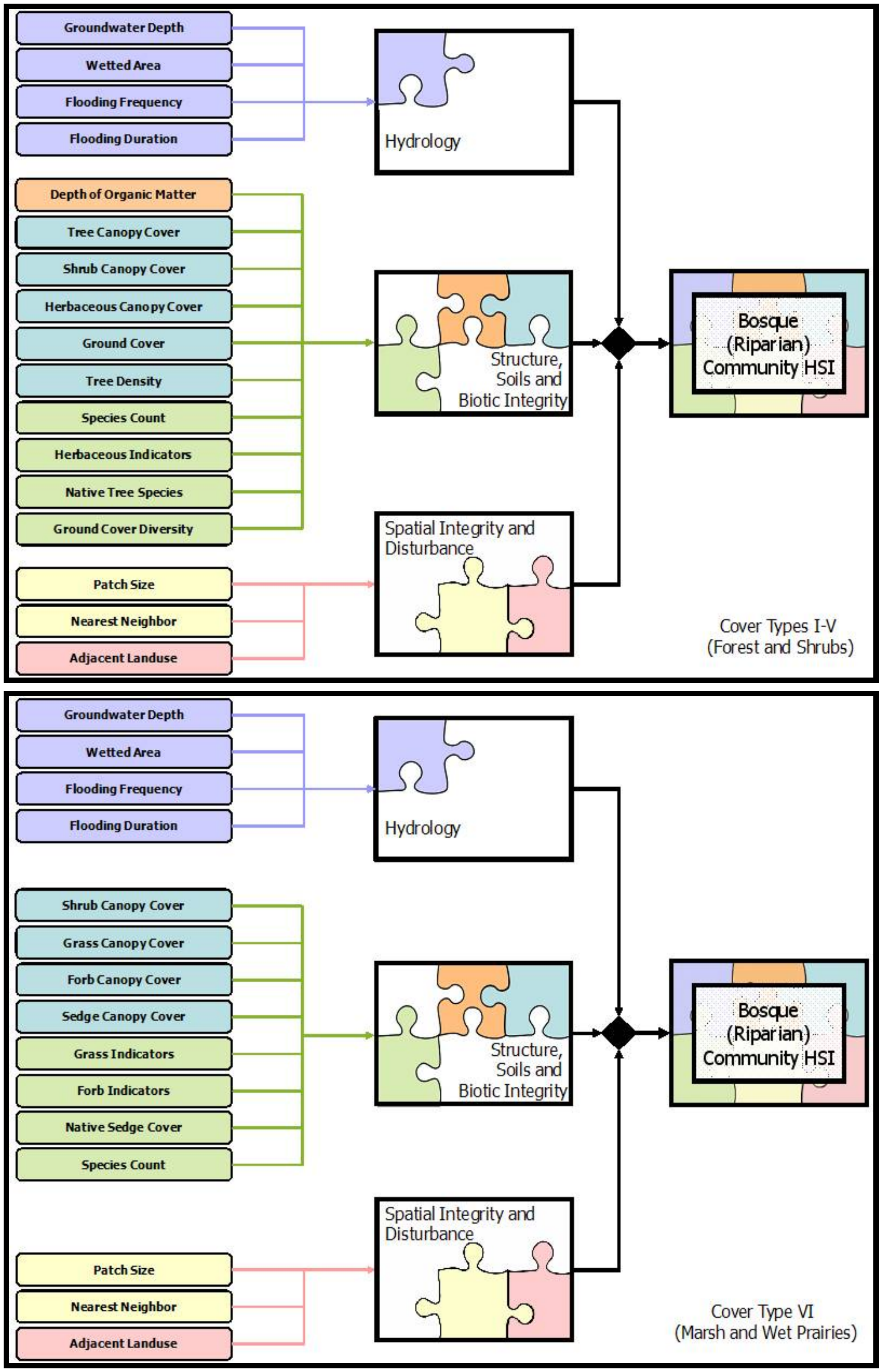


Figure 38. Flow diagram depicting combinations of model components and variables to form the Bosque community index model in the MRGBER study. There are two versions of the model depending on the cover types being evaluated. Types I-V use the upper diagram, and Type VI uses the lower diagram.

Variables were selected as indicators of functionality, and have been color-coded here to correlate their use in specific model components (i.e., purple = hydrologic parameters, orange = soil characteristics, etc.). Again, these model components are combined in a meaningful manner mathematically to characterize the existing reference conditions found in the watershed, and to capture the effects of change under proposed design scenarios (refer to the section below). The rationale for including variables in the model is presented in greater detail in *Chapter 4*.

Model formulas

With this information in hand, ERDC-EL (with review and oversight from the E-Team) used a systematic, scientifically-based, statistical protocol to calibrate the community index model. Modifications to the original algorithms were incorporated into the system as indicated, and the final formulas were made ready for the MRGBER application (Table 3).

It is important to note that the community-based model developed herein does not subscribe to the "limiting-factor" species-based modeling paradigm of the past, but rather attempts to capture the community's integrity based on a series of component indicators (i.e., ***Hydrology***, ***Spatial Integrity/Disturbance***, and ***Biotic Integrity***) that together characterize the functioning of the system. This new function-based approach does not rely on a geometric mean, but rather takes into account the compensatory nature of the system's components. In other words, a degraded bosque might be considered "unsuitable" for a given species, but could potentially have value for others, and therefore would still be considered "functional" (although minimally so). Thus, the hydrologic connection to a bosque could be altered (possibly through channelization or tiling), and would therefore score very low (<0.2) on the Hydrology Component of the model, yet still retain some functionality – it might still provide structure or niches for disturbance-tolerant species. This approach is not new, but is a common strategy for habitat suitability modeling in the scientific literature of late (Brook and Bowman 2006 and references therein, Schluter et al. 2006, Store and Jokimaki 2003, Store and Kangas 2001, Ruger et al. 2005).

Algorithms were only the first step in the model development process. The second step was to calibrate the individual variables that together characterize the model's components using a process that normalizes the individual variable inputs to capture ecosystem integrity on a scale of 0 to 1. Refer to *Chapter 4* of this document for details surrounding the individual variables described above in these algorithms, and to garner details surrounding the sampling and calibration efforts that led to the finalization of this model for the MRGBER study.

Table 3. Index formulas for the MRGBER Bosque community model.

Model Component	Variable Code	CT Code	Formulas
Hydrology (RIP-HYDRO)	DEPTHGW WETTEDAREA FLOODFREQ DURATION	ALL	$\frac{\left(V_{FLOODFREQ} \times V_{DURATION}\right)^{1/2} + V_{DEPTHGW} + V_{WETTEDAREA}}{3}$
Structure, Soils, and Biotic Integrity (RIP-BIOINTEG)	CANTREE CANSHRUB CANHERB DISTBIGTR NATIVETREE INDICATHB SPPCOUNT COVGRND CTGRNDCOV DEPTHOM	TYPE_1 TYPE_2U TYPE_3 TYPE_4T TYPE_4U TYPE_5	$\frac{\left\{3 \times \left[\left(\frac{\left(\left(V_{CANTREE} \times V_{NATIVETREE}\right) \times V_{DISTBIGTR}\right)^{1/2} + V_{CANSHRUB}}{2}\right) \times V_{SPPCOUNT}\right]^{1/2}\right\} + \left(V_{CANHERB} \times V_{INDICATHB}\right) + V_{DEPTHOM} + \left[\left(V_{COVGRND} \times V_{CTGRNDCOV}\right)^{1/2}\right]}{6}$
	CANSHRUB CANGRASS CANFORB CANSEDGE INDICATGR INDICATFB NATIVESDG SPPCOUNT	TYPE_6T TYPE_6U TYPE_6W	$\frac{\left(V_{CANSHRUB} \times V_{SPPCOUNT}\right) + \left(V_{CANGRASS} \times V_{INDICATGR}\right) + \left(V_{CANFORB} \times V_{INDICATFB}\right) + \left(V_{CANSEDGE} \times V_{NATIVESDG}\right)}{4}$
Spatial Integrity and Disturbance (RIP-SPATIAL)	PATCHSIZE TYPDISTURB DISTPATCH	ALL	$\frac{\left[2 \times \left(V_{PATCHSIZE} \times V_{DISTPATCH}\right)^{1/2}\right] + V_{TYPDISTURB}}{3}$
Overall Habitat Suitability Index (HSI):			$\frac{V_{BBIOTA} + V_{BWATER} + V_{BLANDSCPAPE}}{3}$

4 HSI Model Sampling and Calibration Protocols

This chapter describes the variables employed within the bosque riparian community index model. In an effort to support the future use of the model, detailed sampling protocols are included, as well as rationale for the incorporation of each variable into the model, and scientific literature that supports inclusion of the variables. In order to use these parameters within a traditional HEP context, each variable must be normalized or scaled on a 0 to 1 range. This document describes the normalization process in some detail, and Appendix E fully documents the final index curves.

HSI model variables selection rationale

As mentioned previously, ERDC-EL used a systematic, scientifically-based, statistical protocol to develop and calibrate the community model for the study using an iterative approach that involved the selection of reference sites from across the watershed and a sampling scheme that obtained numbers to assure model precision. The variables associated with the bosque riparian community model (and justifications for their inclusion in the model) are provided in Table 4.

Baseline ecosystem characterization for this study included gathering data on water quality, hydrology, substrate conditions, flora, and fauna, and to the greatest extent possible, identifications of underlying stressors in the region. In particular, land-use activities, physical habitat alterations, and native species were identified. In addition to the physical and chemical characteristics of the study area, land ownership and regulatory jurisdictions played an important role in determining opportunities for restoration. Some of this information was geographically based and was assessed using documented protocols in an ArcGIS environment (see below). Field data were collected from the reference sites between May and July of 2005. The landscape-level data and historical data were subsequently generated over the course of the next several years (2005-2007). These datasets, in turn, were used to characterize the baseline conditions of the study area.

Table 4. Variables and rationales for association in the bosque riparian community index model.

Code	Variable Description	Rationale
CANFORB	Canopy Cover of Forb Species (%)	Three distinct layers can be described in any terrestrial ecosystem (including wetlands): groundcover, understory (i.e., mid-canopy) and overstory (i.e., upper canopy). The presence of each layer offers a niche for community associations. High structural complexity promotes diversity in ecosystems. Species rarely occupy area – they occupy three-dimensional space (Giles 1978). The abundance of vegetative structure greatly influences the abundance and diversity of animals in both wetland and terrestrial ecosystems - complex habitats accommodate more species because they create more ways for species to survive (Norse 1990). Furthermore, studies indicate that physical structure may prevent generalist foragers from fully exploiting resources and thus promoting the coexistence of more species (Werner 1984). In particular, vertical stratification diversification of forests produces stratification of light and temperature, as well as providing intricate spaces for shelter and food sources for species. Thus, structural complexity plays a critical role in the presence of microclimate, food abundance, and cover that affect organism fitness (Cody 1985). The predominance of woody vegetation in riparian ecosystems provides an important habitat value, especially near grasslands, deserts, and farmlands where extensive forests are lacking (Brinson et al. 1981). Riparian forest habitats have considerable vertical structure, foliage height diversity, and foliage density, which contribute to wildlife diversity and abundance. By definition, forested wetlands contain tree species in their upper and lower canopies, and tree canopy in particular exceeds 50% coverage in healthy, functioning forested wetlands (Cowardin et al. 1979; Chicago Region Biodiversity Council. 1999; Moulton et al. 1997; Wagner 2004; Jacob et al. 2003; and Texas Parks and Wildlife Department 2007). **These variables were designed to capture the multiple layers of a healthy bosque ecosystem capturing not only future successional changes in the community, but offering target thresholds for restoration activities.**
CANGRASS	Canopy Cover of Grass Species (%)	
CANHERB	Canopy Cover of Herbaceous Vegetation (%)	
CANSEDGE	Canopy Cover of Sedge Species (%)	
CANSHRUB	Canopy Cover of Shrubs (%)	
CANTREE	Canopy Cover of Overstory Trees (%)	
COVGRND	Ground Cover Present (%)	
CTGRNDCOV	Count of Ground Cover Categories Present	
DISTBIGTR	Distance to Biggest Tree from Sample Point (m)	
DEPTHGW	Depth to Groundwater (ft)	All riparian cottonwoods are dependent on shallow alluvial groundwater that is linked to stream water, particularly in semi-arid regions (Rood et al. 2003). When alluvial groundwater is depleted as a result of river dewatering or groundwater pumping, riparian cottonwoods exhibit drought-stress responses including stomatal closure and reduced transpiration and photosynthesis, altered 13C composition, reduced predawn and midday water potentials, and xylem cavitation. These physiological responses are accompanied by morphological responses including reduced shoot growth, altered root growth, branch sacrifice, and crown die-back. As stream flows become more intermittent, diversity and cover of herbaceous species along the low-flow channel also decline (Stromberg et al. 2007). As groundwater deepens, diversity of riparian plant species (particularly perennial species) and landscape patches are reduced and species composition in the floodplain shifts from wetland pioneer trees (*Populus, Salix*) to more drought-tolerant shrub species including Tamarix (introduced). **The conservation and restoration of cottonwoods will rely on the provision of river flow regimes that satisfy the ecophysiological requirements for survival, growth and reproduction – this variable was included in the model to capture the critical linkage between the bosque and the riparian zone's groundwater table.**

Code	Variable Description	Rationale
DEPTHOM	Depth of Organic Matter (cm)	Soil is mainly composed of minerals and organic matter, like decaying plants and animals, as well as living organisms. The minerals are derived from the weathering of "parent material" - bedrock and overlying sub-soil. The organic matter in soil derives from plants and animals. In a forest, for example, leaf litter and woody material falls to the forest floor. This is sometimes referred to as organic material (http://www.epa.gov/epawaste/conserve/materials/organics/index.htm). When it decays to the point it is no longer recognizable, it is called soil organic matter. When the organic matter has broken down into a stable humic substances that resist further decomposition, it is called humus. Thus soil organic matter comprises all of the organic matter in the soil exclusive of the undecayed material (http://soils.usda.gov/sqi/concepts/glossary.html). Because primary production in riparian zones is extremely complex and variable, organic matter (detritus) processing becomes a key component in maintaining the trophic dynamics of these aquatic ecosystems. In general, primary energy sources for rivers are organic material from riparian vegetation (allochthonous) and organic material generated within the river (Crawford et al. 1993 and numerous references therein). Rivers with high sediment load, such as the Rio Grande, generally have a paucity of aquatic vegetation and thus minimal autochthonous input. Autochthonous input from upstream is a critical source of organic carbon for these systems. Allochthonous input in the Middle Rio Grande supports bacteria and algae that assimilate carbon and thus are vital to the food chain. Coarse organic matter is initially attacked by microbial organisms and converted to organic matter either by natural degradation or shredder macroinvertebrates. Consumer invertebrates, such as detritivores and collectors, use the free organic matter as an energy source and are subsequently consumed by both vertebrate and invertebrate predators. This variable was included in the model as an indicator of the level of primary production within the bosque.
DISTPATCH	Distance to Nearest Patch (aka Nearest Neighbor of Forest or Meadow) (m)	Too often, ecologists perceive habitats as lone entities, when in reality they are interacting, functional components of the landscape (Noss 1991). Landscape connectivity, therefore, involves the linkage of habitats, species, communities and ecological processes at multiple spatial and temporal scales (Noss 1991). Many of the most significant human effects on biodiversity involve changes in the connectivity of habitat (Noss 1991). Human activities can reduce connectivity by creating artificial barriers to species dispersal, leading to isolated populations that become vulnerable to extinction due to reduced access to resources, genetic deterioration, increased susceptibility to environmental catastrophes and demographic accidents, and other problems (Harris 1984; Soule 1987). Connectivity of the landscape mosaic is absolutely necessary for species to survive (Noss 1991). Disturbances periodically make portions of the landscape uninhabitable. Corridors fulfill a “fire escape” function by permitting animals to flee disturbance. Corridors also aid in recolonization of the recovering site by plants and animals. Habitat patches that are isolated from similar habitat patches by great distances or inhospitable terrain are likely to have fewer species than less isolated patches because relatively few individuals of a given species will immigrate into the isolated patch, and fewer mobile species will visit isolated patches because it is inefficient to do so (Hunter 1996). This variable has been included to capture the connectivity of the habitats in the region – indicating species “source” availability.

Code	Variable Description	Rationale
DURATION FLOODFREQ WETTEDAREA	Average Duration of Flooding Events (days) Frequency of Flooding (#/yr) Percent of Polygon that is Wet (%)	Riparian vegetation in dry regions is influenced by low-flow and high-flow components of the surface and groundwater flow regimes. The duration of no-flow periods in the surface stream controls vegetation structure along the low-flow channel, while depth, magnitude and rate of groundwater decline influence phreatophytic vegetation in the floodplain (Stromberg et al. 2007 and references therein). Flood flows influence vegetation along channels and floodplains by increasing water availability and by creating ecosystem disturbance. Floods influence riparian biota by creating ecosystem disturbance, driving geomorphic change, and altering availability of resources including water, light and nutrients (Stromberg et al. 2007 and references therein). In arid regions, floods tend to have high magnitude but short duration. The rapidly peaking and receding waters of small floods create minor disturbance and provide a transitory water source. Floods of greater magnitude and longer duration can shape vegetation structure for decades, and mediate water availability both through short-term hydrologic processes (overbank soil wetting, groundwater recharge) and longer-term geomorphic processes (channel incision, floodplain aggradation and degradation, deposition of course versus fine sediments) (Stromberg et al. 2007 and references therein). On impounded rivers, changes in flood timing can simplify landscape patch structure and shift species composition from mixed forests composed of Populus and Salix, which have narrow regeneration windows, to the more reproductively opportunistic Tamarix. If flows are not diverted, suppression of flooding can result in increased density of riparian vegetation, leading in some cases to very high abundance of Tamarix patches (Stromberg et al. 2007 and references therein). Cottonwood and willow seedlings are small and particularly vulnerable to drought stress and consequently altered flow regimes often severely suppress seedling recruitment and this provides a predominant factor impacting riparian cottonwood forests (Braatne et al. 2007 and references therein). Since cottonwoods are relatively short-lived trees, typically dying within a century and seldom surviving beyond two centuries, ongoing reproduction is essential to provide continuity of riparian cottonwood forests (Braatne et al. 2007 and references therein). The recruitment of cottonwood seedlings is dependent on dynamic fluvial and geomorphic processes (Braatne et al. 2007 and references therein). Seasonal flow patterns including periodic spring flooding produce moist and barren substrates that are required for seedling recruitment (Braatne et al. 2007 and references therein). After germination, the roots of young seedlings must keep pace with the receding soil moisture that is closely coordinated with the declining river stage (Braatne et al. 2007 and references therein). Thus, if river levels decline abruptly, young seedlings succumb to drought stress. Older cottonwoods also benefit from periodic flooding that recharges the alluvial groundwater table (Braatne et al. 2007 and references therein). **These variables were included in the model to capture the critical hydrologic pulsing necessary to support riparian bosque recruitment and maintenance.**
INDICATFB INDICATGR	Percent of Forb Canopy that is an Undesirable Indicator Species (%) Percent of Grass Canopy that is an Undesirable Indicator Species (%)	Many of the most dramatic examples of population fluctuations affecting ecological processes involve the invasion of non-native (exotic) species (USEPA 1999). Through direct biotic interactions (predation and competition) and indirect interactions (ecological engineering and habitat modification), invasive species can disrupt the natural population dynamics of native species (USEPA 1999). Invasives can include noxious plants (i.e., plants that are listed by a state because of their unfavorable economic or ecological impacts), non-native, and native plants. Invasive plants may impact an ecosystem's type and abundance of species, their interrelationships, and the processes by which energy and nutrients move through the ecosystem. These impacts can

Code	Variable Description	Rationale
INDICATHB	Percent of Herbaceous Canopy that is an Undesirable Indicator Species (%)	influence both biological organisms and physical properties of the site (Olson 1999). The effects range from slight to catastrophic responses depending on the species involved and their degree of dominance. Invasive species may adversely affect a site by increased water usage (e.g., salt cedar (tamarisk) in riparian areas) or rapid nutrient depletion (e.g., high nitrogen use by cheatgrass). Some invasive plants (e.g., knapweeds) are capable of invading undisturbed climax bunchgrass communities (Lacey et al. 1990) further emphasizing their use as an indicator of new ecosystem stress. Even highly diverse, species-rich plant communities are susceptible to exotic species invasion (Stohlgren et al. 1999). **These variables then were included to capture the presence/absence of invasives indicating a level of functionality (when compared to the reference setting) indicative of disturbance and competition both now and in the future.**
NATIVESDG NATIVETREE SPPCOUNT	Percent of Sedge Canopy that is a Desirable Indicator Species (%) Percent of Tall Overstory Tree Canopy that is a Native Species (%) Number of Native Tree and Shrub Species (presence/absence)	The assessment of ecosystem integrity based on a single index will be insufficient to account for all relevant aspects (Herman et al. 2001). Species richness (number of species) by itself can also be an insensitive indicator of habitat quality since it is possible for a degraded site to support a similar or greater number of taxa than an intact, high quality site. Six measures of biological integrity for wetlands have been suggested by Keddy et al. (1993). These include species diversity, indicator guilds, exotic species, rare species, plant biomass, and amphibian biomass. Keddy et al. (1993) view diversity as an essential indicator of integrity, but also recommend assessing guild diversity. **These variable were included to capture the number of "native" species at the site in an attempt to capture several of these key measures, namely species diversity (richness and eveness), presence specifically of "indicators," and presence of these species tied to a specific community or guild (namely ground vegetation) - the assumption being that higher numbers of native species present signifies ecosystem health and integrity.**
PATCHSIZE	Size of Patch (ac)	The size of habitat patches has important implications for ecological integrity (USEPA 1999). Fragmentation of habitats has been implicated in the decline of biological diversity and the ability of ecosystems to recover from disturbances (Flather et al. 1992). Large patches have more species because they provide a greater number and variety of niches. Large patches are more likely to have both common and rare species, while small patches are more likely to have only common species (i.e., area-sensitive species will be excluded in smaller patches) (Hunter 1996). Small habitat patches (e.g., habitat islands) have fewer species than large patches, and are more susceptible to extinction. Area-sensitive species that cannot maintain populations in limited areas of otherwise high quality habitat will avoid patches purely on the basis of size (USEPA 1999). Species with small home ranges, such as songbirds, may also avoid small fragments if they prefer the interior of large habitat patches (Robbins et al. 1989) or select patches large enough to support other members of their species (Stamps 1991). Larger tracts/patches of habitat containing larger populations of targeted species have better functionality and suitability than smaller tracts/patches of habitat with small numbers of species (USEPA 1999). Larger patch fragments have a higher core-to-edge ratio. The greater the distance between larger and smaller patches, the more inefficient it becomes for mobile species to visit the smaller patches, affecting the number and diversity of species (Hunter 1996).

Code	Variable Description	Rationale
		This variable was included to characterize both the patch size of the various habitats as well as to capture the future urbanization threat to these ecosystems if preventative measures are not taken in the recommended plans.
TYPDISTURB	Type of Human Disturbance (aka Adjacent Landuse Within 2 km)	Ecosystems do not exist in a steady-state; they are dynamic, each possessing a characteristic composition structure and function that have adapted to natural disturbances over long periods of time. At the landscape level, natural disturbances destroy patches of vegetation and restart plant succession. Human activities (both onsite and offsite) that deviate from these patterns affect individual species (and through biotic interactions many other species and ecological processes) by direct exploitation, habitat elimination, and modification of ecological processes (USEPA 1999). By changing the access of species to their food, shelter, and reproduction, human activities initiate a cascade of biotic interactions that can affect entire ecosystems (USEPA 1999). Impervious surfaces prevent infiltration and direct water away from subsurface pathways to overland flow, increasing the flashiness of streams. Urbanization and suburbanization commonly exceed the threshold of approximately 10 to 20 percent impermeable surface that is known to cause rapid runoff throughout the watershed (Center for Watershed Protection 1994). In a heavily urbanized watershed, stream channelization and a large amount of impervious surface result in rapid changes in flow, particularly during storm events. These artificially high runoff events increase flood frequency (Beven 1986), cause bank erosion and channel widening (Hammer 1972), and reduce baseflow during dry periods. Agricultural practices also greatly affect hydrologic patterns (USEPA 1999). Clearing forest and prairie environments generally decreases interception of rainfall by natural plant cover and reduces soil infiltration resulting in increased overland flow, channel incision, floodplain isolation, and headward erosion of stream channels (Prestegaard 1988). Draining and channelizing wetlands directs flow more quickly downstream, increasing the size and frequency of floods, and reducing baseflow (USEPA 1999). Such activities can actually increase the magnitude of extreme floods by decreasing upstream storage capacity and accelerating water delivery. Human activities, such as land clearing and erosion, can cause the loss of nutrients (e.g., phosphorus), disrupt natural cycling of nutrients, and limit ecosystem productivity (USEPA 1999). At the same time, agriculture and industry can discharge excessive amounts of nutrients (e.g., nitrogen) into natural ecosystems and drastically change their trophic structure, and degrade water quality. This variable was added to the model to capture the effects of human activities immediately outside of the habitat area, and can be used as an indication of urban pressures on the remaining relictual ecosystems in the future.

To assure adequate sampling size, the District was asked to locate at least three sites per cover type spanning the range of reference conditions and representing the relative variation found across the system (described earlier in the reference-based section above). Again, an attempt was made to evenly distribute these sites across the entire watershed. To reduce data collection variability, all data were collected by a single three-person sampling team (a recorder and two data collectors). To the greatest extent possible, underlying stressors in the region were described in the notes section of the field data collection sheets. In particular, land-use activities, physical habitat alterations, and indicator species were described in detail.

A reference-based modeling approach

To begin, the E-Team developed hypothetical mathematical algorithms to relate the various components to the ecosystem processes occurring throughout the watershed in this community. To test these concepts, a series of reference sites[1] provided relevant feedback and verification of the model's conceptual architecture.

Background on reference-based approaches

The following information was provided to the authors in a workshop hosted by ERDC-EL in the summer of 2008 under the Ecosystem Management and Restoration Research Program's Environmental Benefits Analysis initiative by Drs. Ronald (Dan) Smith and John Nestler. In that workshop, a draft manuscript was circulated to the participants for review and comment. Excerpts from that paper are provided here and local knowledge of the bosque system's reference conditions are injected where relevant.

Reference sites in this instance refer to multiple sites in a defined geographic area (the reference domain) that were selected to represent a specific type of ecosystem (i.e., arid riparian forests and wetlands or bosques). Reference sites are most commonly described as natural settings with minimal human disturbances (Hughes 1994, Bailey et al. 2004a, Chessman and Royal 2004, Intergovernmental Task Force on Water Quality Monitoring 2005). Reference-based conditions are therefore the range of

1 Choosing the relevant reference conditions in a region is a matter of judgment (Andreasen et al. 2001). In some instances, the natural state might be reconstructed from historic records or based on scientific knowledge such as reconstruction of potential vegetation. ERDC-EL assisted the Albuquerque District in locating a series of 27 sample sites across the entire study area that were considered both reference standard (optimal) or degraded (sub-optimal) and represented the range of conditions existing within the reference domain.

physical, chemical, and biological values exhibited within the reference sites. When reference sites are characterized as undisturbed ecosystems, reference conditions exhibit at a range of values that reflect the spatial and temporal variability that commonly occur in natural ecosystems (Swanson et al. 1993; Morgan et al. 1994; White and Walker 1997; Landres et al. 1999). When reference sites include altered or disturbed ecosystems (as is the case in most urban-based ecosystem restoration efforts such as the MRGBER), the reference conditions exhibit a wider range of values that reflect both natural variability and variability due to human activities. In these instances, optimal conditions or "virtual" references can be established using a variety of techniques including literature values, historical data, paleoecological data, and expert opinion (Society for Ecological Restoration International (SERI) 2004; Ecological Restoration Institute 2008). Regardless of how reference conditions are established, ecosystem restoration evaluations can use the reference-based approach as a template for model development, restoration planning, and alternative analysis.

Various types of reference-based approaches have been developed for a variety of ecosystems including streams (Barbour et al. 1999, Karr and Chu 1999, Bailey et al. 2004b), large rivers (Angradi 2006, Flotemersch et al. 2006), wetlands (Smith et al. 1995, Brinson and Rheinhardt 1996, Smith 2001, USEPA 2002), grasslands (Prober et al. 2002), forests (Fule et al. 1997, Moore et al. 1999, Tinker et al. 2003, Ecological Restoration Institute 2008), tidal marshes/estuaries (Findlay et al. 2002, Merkey 2003), and coral reefs (Jameson et al. 1998). Reference-based approaches have also been used to evaluate ecosystems in a landscape or watershed context (Warne et al. 2000, Andreasen et al. 2001, Reinhardt et al. 2007, Wardrop et al. 2007, Whigham et al. 2007, Smith 2008).

Reference site selection strategy

A one-page handout was provided to the Albuquerque District early in the planning process to assist in the selection of reference sites for the bosque model. The following is a synopsis of the directives given to the team:

A. Definitions

1) ***Reference*** sites serve several purposes in HEP. First, they function as the physical representation of the communities from the region that can be observed and measured repeatedly. Second, they make it possible to establish the range of variability exhibited

by the measures of the model variables, which make it possible for calibration of variables and indices. Third, they serve as a template for restoration by providing design specifications.

2) ***Reference standard*** areas are those optimum conditions in the region that are then used to establish the highest standard of comparison for calibrating assessment model variables and indices. In HEP, the least altered areas in the least altered landscapes are selected as *reference standard* wetlands. This is based on the assumption that these areas sustain the highest level of function across the suite of habitats within the community that are inherent to the system.

B. General Selection Strategy

1) ***Conduct field reconnaissance*** to screen potential candidate reference sites. The objective is to identify sites that represent the range of conditions that exist in the reference area from highly altered sites in highly altered landscapes to unaltered (pristine) sites in unaltered landscapes.
2) ***Determine the number*** of reference sites to be included. A variety of factors influence the number of reference sites to be included in the process. Large projects will require more reference sites. Reference areas with a wide variety of alteration scenarios will require more sites. Detail of resolution to detect the types of impacts that typically affect riparian areas in the region is another factor. Lastly, the ideal number of sites dictated by the foregoing considerations must be balanced against the realities of budgets, time, and personnel.

C. Criteria for Defining Reference Conditions

1) Must be politically palatable and reasonable;
2) Must include a large number of sites from the region;
3) Must represent important aspects of pre-historical conditions;
4) May use minimal disturbance as the surrogate for pre-historical conditions, given the difficulty of establishing pre-historical conditions;
5) Must be uniform across political boundaries and bureaucracies (e.g., Federal, State, and local); and

6) When the areas have experienced extensive alteration, it may be possible to reconstruct a reference standard area using historical accounts and photography.

Desired reference standard conditions

Based on the inventory and reconnaissance efforts completed by the District in early 2005, the reference standard conditions for the Middle Rio Grande bosque community can be characterized in the following manner:

Hydrology - Channel characteristics (channel pattern, sinuosity, and width) are not altered by human disturbances that cause changes in hydroregime (flood frequency, duration, or magnitude) or sediment transport. The sediment transport, channel morphology, width, and sinuosity patterns are natural. The river channel should exhibit deposition and erosion of soils creating a wide floodplain characteristic of the area. The flood flow should mimic the climatic/natural regime. Vegetation is present to resist flow downstream, and together with topographic relief and subsurface water flow, promotes surface water storage. The flood-prone area is undisturbed by humans. Surface hydraulic connections exist between the bankfull channel and the flood-prone area. Surface water ponds for more than one day. Side channels are unmodified and connected to the main reach. If the river system has been altered in the past, the system has attained a stable condition for those characteristics and is no longer undergoing degradation. The depth of saturated sediment is near the surface of the wetland. Groundwater and the managed water supply must be appropriate to establish and maintain a diverse cover type.

Biogeochemical - A range of vegetation types and sediment combined with suitable topographic relief support detention of particulates. Sufficient water flow through the riparian zone (surface and subsurface) must be evident as well as substrates with enough silt to adsorb elements, promote propagule recruitment, and supply organic materials. In addition, presence of organic matter indicates nutrient cycling occurring within the bosque.

Vegetation - There must be an abundance of native trees, shrubs, and herbaceous vegetation. Invasive plant species are absent. Guild representatives (i.e., indicators) must include a wide variety of growth forms (trees, shrubs, vines, grasses, forbs, algae, and lichens). Plant vertical configuration and foliage profile (canopy cover) must represent a variety of layers.

Vegetation provides vertical and horizontal connectivity for the length of the system. All age classes of trees (seedlings, saplings, and trees) must be represented. Biotic legacies from preceding bosque forests, propagules from adjacent cottonwood stands, forest structuring processes, and the generation of spatial heterogeneic complexes combined to produce both overall compositional diversity and patch diversity (habitat breadth).

Spatial configuration – Spatially explicit landscape characteristics within the bosque setting associated with patch geometry and distribution are maximized. Landscape simplification is absent – a mosaic or heterogeneic suite of habitat types are present in sufficient size and numbers to promote both core area stability and edge diffusion (a blurring of the edge contrast). Habitat connectivity is evident and supports the persistence of both plant and animal populations. Distances between high quality patches are minimized, and a mixture of age classes are present within a reasonable distance of one another to promote niche diversification and offer escape routes during stochastic disturbances. Land adjacent to the project is undeveloped and unperturbed by human disturbances such as agricultural activities.

Reference site selection

Once the inventory and reconnaissance were completed, the E-Team used the strategy outlined above to filter and screen the potential sites down to a manageable number. To assure adequate sampling size, the District was asked to locate at least three sites per cover type spanning the range of reference conditions and representing the relative variation found across the system (described earlier in the reference-based section above). Again, an attempt was made to evenly distribute these sites across the entire watershed. To reduce data collection variability, all field data were collected by a single three-person sampling team (a recorder and two data collectors). To the greatest extent possible, underlying stressors in the region were described in the notes section of the field data collection sheets. In particular, land-use activities, physical habitat alterations, and indicator species were described in detail. Their goal was to identify, prioritize, and then select sites across the study area that were considered either "high (**H**)," "medium (**M**)," or "low quality (**L**)" based on expert opinion (Table 5).

Table 5. Middle Rio Grande Reference Sites.

Reach	Reference Site	Site No.	Cover Type	Expected Value (E-Team Estimated)
Reach 1	Corrales	28	TYPE_2U	High
	Corrales	29	TYPE_6W	High
	Corrales	30	TYPE_6W	High
	Corrales	33	TYPE_4U	Low
	Alameda	34	TYPE_4U	Medium
	Alameda NE	36	TYPE_6U	Medium
Reach 2	Paseo NE	1	TYPE_1	High
	Paseo NE	2	TYPE_3	High
	Paseo NE	3	TYPE_6T	Low
	Paseo SE	4	TYPE_4T	Medium
	Paseo SE	5	TYPE_3	Medium
	Paseo SW	6	TYPE_2T	Medium
	La Orilla N	7	TYPE_6T	Medium
	La Orilla S	8	TYPE_6T	Medium
Reach 3	Oxbow N	9	TYPE_5	Low
	Oxbow M	10	TYPE_6W	Medium
	Oxbow S	11	TYPE_2U	Medium
	RGNC N	12	TYPE_2U	Medium
	RGNC S	13	TYPE_4T	Medium
	RGNC W	14	TYPE_1	Low
	Montano SW	15	TYPE_2T	Medium
Reach 4	Bridge SW	16	TYPE_4T	Medium
	AOP	17	TYPE_2U	Medium
	Rio Bravo NE	18	TYPE_4U	Medium
	Tingley Bar	35	TYPE_6U	High
Reach 5	Harrison levee	20	TYPE_1	Medium
	Harrison bar	21	TYPE_6U	High
	SDC North levee	22	TYPE_2T	Low
	SDC North river	23	TYPE_5	High
	SDC South	24	TYPE_5	Low
	Price's Dairy	26	TYPE_3	Medium

These initial rankings were based upon the consensus of the "on-the-ground" resource managers that had actual knowledge of each site's level of disturbance, species composition, land ownership, and the presence or absence of hydrologic alterations. An attempt was made to evenly distribute the site selection across the study area. Thirty-one sites were considered either reference standard (optimal) or sub-optimal and were chosen to represent the range of conditions existing within the reference domain (Figure 39).

Figure 39. Bosque reference sites in the MRGBER study area used to calibrate the Bosque community index model.

Sampling protocol – Site preparations

A standardized approach was developed to collect all field data. Using a somewhat subjective protocol (taking a random number of footsteps in a random direction into each reference site), a central sample point in the field was established by the team, and a rebar stake was placed in the ground at that point. This point served as both a permanent plot marker and as the center point for two, perpendicularly aligned 50-m sampling transects, which formed a “cross” configuration (Figure 40).

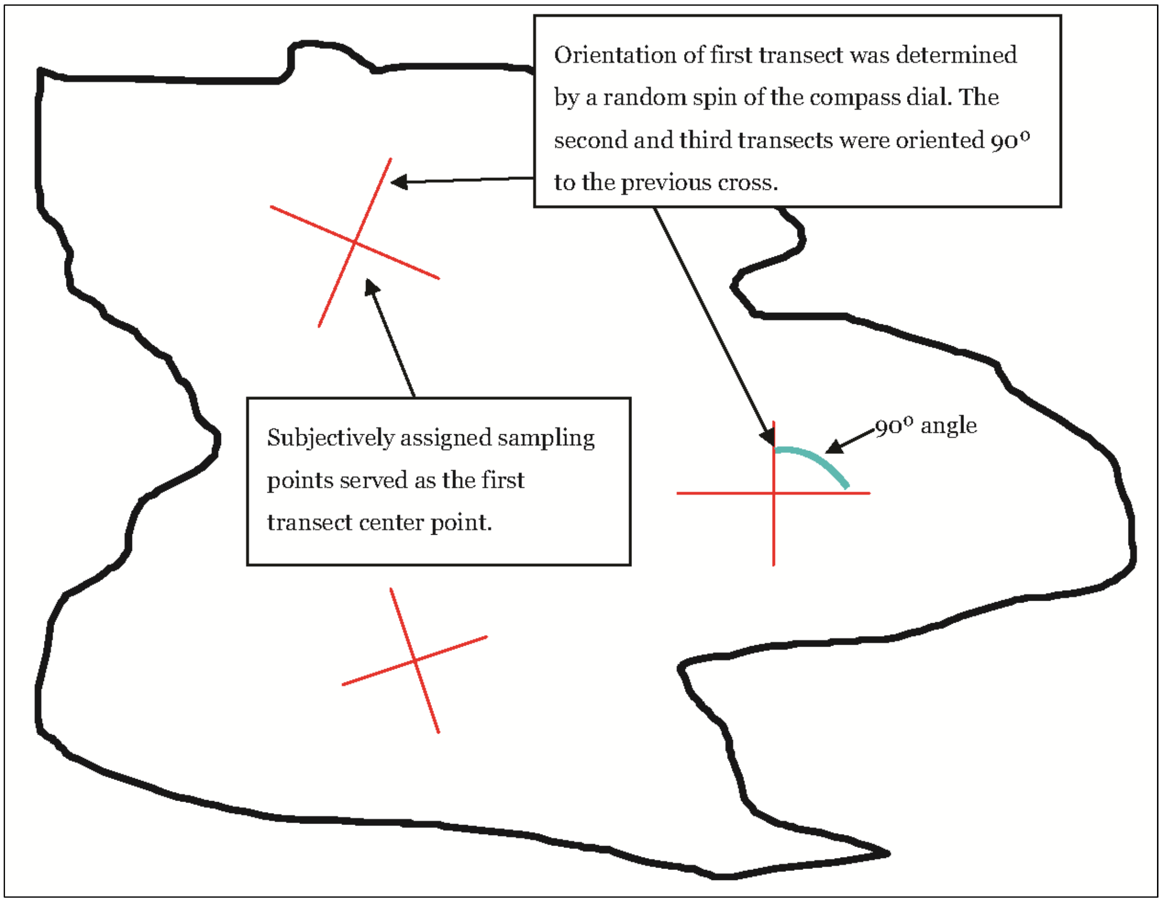


Figure 40. Illustration of the MRGBER baseline sampling design for the Bosque Riparian HSI model components. Up to three 120-m plots (crosses) were established in a single vegetation polygon.

The orientation of the first 50-m tape in the first “cross” was determined randomly by standing over the central point and making an unobserved spin of a compass dial. The next cross was oriented a random distance away (again through the use of random steps and random compass bearings) at a 90° angle to the previous cross. In this manner, three crosses were established per polygon (up to 300-m sampling transect length per polygon) when polygon size/shape permitted. As each cross was established, a GPS

was used to document the coordinates (northing/easting) of the central sample point and entered into a GIS upon returning to the office.[1]

On a technical note, while the sampling distance along each transect was 50 m, each transect was actually extended to 60 m because the 5-m circumference around the center rebar was avoided to restrict measurement overlap (refer to the green square in Figure 41 below), and because this area was trampled to some extent during plot setup.

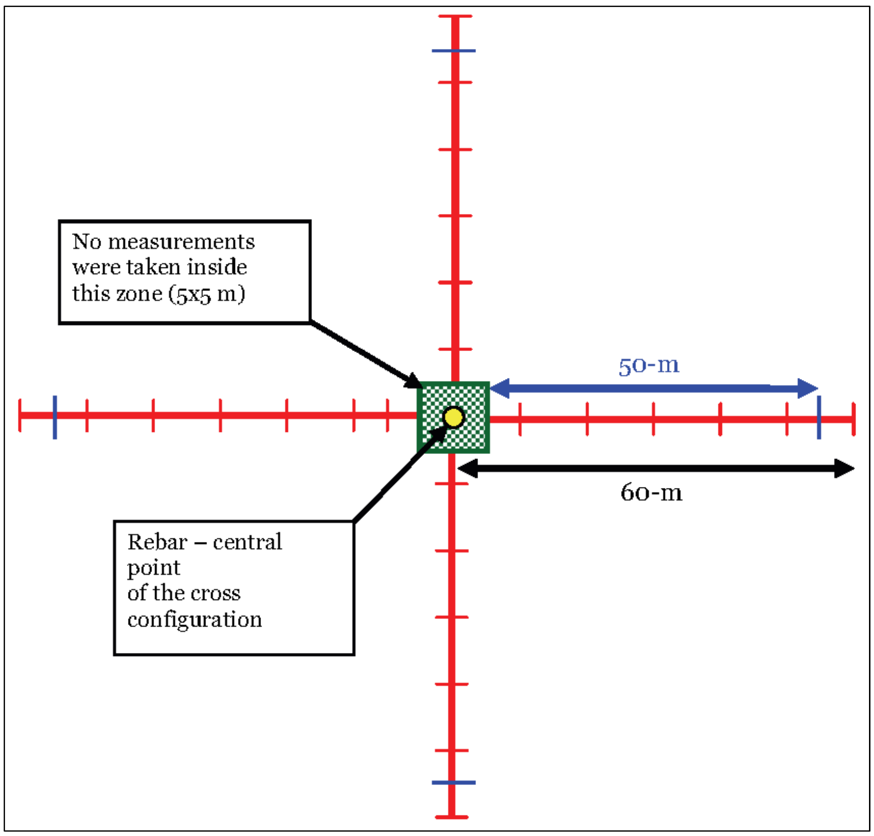


Figure 41. Details of the “cross” configuration used to sample the vegetative variables in the MRGBER study.

Vegetative data collection

Table 6 below identifies the sampling techniques used to measure the individual HSI variables in the 2005 field effort. For more details regarding these protocols, refer to Appendix F.

1 This procedure will allow researchers and managers to return to these points in the future to facilitate monitoring activities.

Table 6. Field sampling protocols summarized for the variables associated with the Bosque Riparian community index model.

Code	Variable Description	Sampling Methodology and Data Management	Cover Type Applicability
CANFORB	Canopy Cover of Forb Species (%)	Point-intercept was used to measure the numerous herbaceous canopy cover parameters (percent grass, sedge, forbs, and overall herbaceous canopy cover). To increase efficiency and considering the project goals, the field team only recorded canopy "hits" according to plant life-form (i.e., grass, forb, sedge, or rush). The only exception to this rule will be if the pin made contact with a highly desirable or undesirable plant species ("indicator species") (refer to INDICATFB, INDICATGR, INDICATHB, and NATIVESDG below). Canopy "hits" per life-form (for Type 6's) or for herbaceous canopy in general (for Types 1-5) were converted to a value of 100 and "misses" were converted to zeroes. The average of these values was then calculated per cross (100-m sample point) and the three crosses were averaged to generate a mean score per cover type.	TYPE_6T TYPE_6U TYPE_6W
CANGRASS	Canopy Cover of Grass Species (%)	Same as CANFORB above	TYPE_6T TYPE_6U TYPE_6W
CANHERB	Canopy Cover of Herbaceous Vegetation (%)	Same as CANFORB above	TYPE_1 TYPE_2T TYPE_2U TYPE_3 TYPE_4T TYPE_4U TYPE_5
CANSEDGE	Canopy Cover of Sedge Species (%)	Same as CANFORB above	TYPE_6T TYPE_6U TYPE_6W
CANSHRUB	Canopy Cover of Shrubs (%)	Aerial cover of shrubs was recorded using a line-intercept technique. Canopy cover was measured (cm) along the line intercept transect by noting the point along the tape where the canopy began and the point at which it ended based on a technique described by Elzinga et al. (1998). For this study, a minimum continuous distance along the tape for recording a shrub was set at 0.5 m. After all line-intercept data were recorded for a plot (plot = two 50-m transects), the intercepts for each shrub species were divided by the total line length sampled (100 m) to get the percent shrub cover for each cross. The three crosses were averaged to generate a mean score per cover type.	ALL TYPES
CANTREE	Canopy Cover of Overstory Trees (%)	Aerial cover of trees was recorded at 2-m intervals along each transect using a vertical densitometer. A vertical densitometer (a.k.a. "moosehorn") provided a point measure of canopy cover using a crosshairs and a bubble level that allowed the observer to determine whether canopy is present directly over a position along the transect. Species identity was noted, and used to generate the NATIVETREE values as well (see below).	TYPE_1 TYPE_2T TYPE_2U TYPE_3

Code	Variable Description	Sampling Methodology and Data Management	Cover Type Applicability
		Canopy “hits” were converted to a value of 100 and “misses” were converted to zeroes. The average of these values was then calculated per cross (100-m sample point) and the three crosses were averaged to generate a mean score per cover type.	TYPE_4T TYPE_4U TYPE_5
COVGRND	Ground Cover Present (%)	As with aerial herbaceous plant cover (*CANHERB* above), ground cover was measured at 2-m intervals along each transect using the point-intercept method. Ground cover was reported as one of six general categories: 1. bare soil 2. litter (leaves or other non-living plant tissue, accept for “woody” plant material) 3. mulch (shredded woody debris created by mulching tractors) 4. live basal vegetation (the pin rests on the basal portion of a live plant) 5. downed woody vegetation <3-in. diameter (shrub or tree stem) 6. downed woody vegetation >3-in. diameter (shrub or tree stem/log) Ground cover “hits” were converted to a value of 100 and “misses” were converted to zeroes. The average of these values was then calculated per cross (100-m sample point) and the three crosses were averaged to generate a mean score per cover type.	TYPE_1 TYPE_2T TYPE_2U TYPE_3 TYPE_4T TYPE_4U TYPE_5
CTGRNDCOV	Count of Ground Cover Categories Present	Refer to COVGRND above, but in this instance, counts of ground cover categories were recorded. The average of these values was then calculated per cross (100-m sample point) and the three crosses were averaged to generate a mean score per cover type.	TYPE_1 TYPE_2T TYPE_2U TYPE_3 TYPE_4T TYPE_4U TYPE_5
DEPTHOM	Depth of Organic Matter (cm)	Depth of organic matter (O-horizon) will be measured to the nearest 0.25 cm recorded at 2-m intervals along each transect. The average of these values was then calculated per cross (100-m sample point) and the three crosses were averaged to generate a mean score per cover type.	ALL TYPES
DISTBIGTR	Distance to Biggest Tree from Sample Point (m)	The point-centered quarter method was known to be a frequently used distance method to sample forest communities (Bonham 1989; Cottam and Curtis 1956; Elzinga et al. 1998; Krebs 1999). After a sampling point along a transect was located (in this case, at the end of each cross arm), the area around those points was split into four 90° quadrants (quarters) and the distance to the nearest tree and root-sprout in each quarter was estimated with an optical rangefinder. The average distance for all four quadrats (cross-terminus’) were calculated per cross (100-m sampling point) and the three crosses were averaged to generate a mean score per cover type.	TYPE_1 TYPE_2T TYPE_2U TYPE_3 TYPE_4T TYPE_4U TYPE_5

Code	Variable Description	Sampling Methodology and Data Management	Cover Type Applicability
INDICATFB	Percent of Forb Canopy that is an Undesirable Indicator Species (%)	The point-intercept approach was used to measure these more particular herbaceous canopy cover parameters, but the sampling team was required to record species identity when undesirable indicators or desirable species were encountered. For a list of undesirable and desirable (native) species per life-form, refer to Appendix F. Canopy “hits” per life-form (for Type 6’s) or for herbaceous canopy in general (for Types 1-5) were converted to a value of 100 and “misses” were converted to zeroes. The average of these values was then calculated per cross (100-m sample point) and the three crosses were averaged to generate a mean score per cover type.	TYPE_6T TYPE_6U TYPE_6W
INDICATGR	Percent of Grass Canopy that is an Undesirable Indicator Species (%)	Same as INDICATFB above	TYPE_6T TYPE_6U TYPE_6W
INDICATHB	Percent of Herbaceous Canopy that is an Undesirable Indicator Species (%)	Same as INDICATFB above	TYPE_1 TYPE_2T TYPE_2U TYPE_3 TYPE_4T TYPE_4U TYPE_5
NATIVESDG	Percent of Sedge Canopy that is a Desirable Indicator Species (%)	Same as INDICATFB above	TYPE_6T TYPE_6U TYPE_6W
NATIVETREE	Percent of Tall Overstory Tree Canopy that is a Native Species (%)	The percent of “hits” recorded as desirable (native) species under the aerial canopy protocol for trees above (CANTREE) was used to generate an average for each of the 100-m sample points (i.e., crosses), and the three crosses were averaged to generate a mean score per cover type.	TYPE_1 TYPE_2T TYPE_2U TYPE_3 TYPE_4T TYPE_4U TYPE_5
SPPCOUNT	Number of Native Tree and Shrub Species (presence/absence)	Same as NATIVETREE	ALL TYPES

Spatially explicit data collection

Landscape variables were determined based on a combination of onsite reconnaissance, interpretation of maps and aerial photos, and analysis of GIS data layers using ArcGIS 9.2. The GIS information (e.g., vegetative cover, access points along the river, bike trails, kiosks, etc.) was collected by ERDC-EL from various sources including the District itself, Bernalillo County, New Mexico Resource Geographic Information System (http://rgis.unm.edu/) and the U.S. Census Bureau (http://www.census.gov/) between 2005 and 2008 (June 2008). A personal geodatabase was developed to organize and house the data for quick retrieval.

June 2005 QuickBird aerial imagery in NAD83, U.S. Survey Feet, New Mexico State Plane Central was used to complete the baseline cover type mapping exercises. The Albuquerque District was responsible for the development of *Hink and Ohmart* classification vegetation mapping (with ground-truthing) from this imagery in 2006. These maps were then digitized and converted into shapefiles with attributes including H&O Codes (C/CW,MH5 , etc.) and acreage. Any questions surrounding this information should be addressed to the Albuquerque District's Ondrea Hummel (refer to Appendix D for point of contact information). ERDC-EL developed expression files to crosswalk the H&O codes to the HSI cover type classifications associated with the model (TYPE_1, TYPE_2T, etc.) (Appendix F). Gaps and overlaps were cleaned, and cover type acreages were generated and exported to spreadsheets at the reach level for the entire study area for use in the HSI model.

The spatially-explicit landscape metrics in the Bosque Riparian HSI model are directly dependent on the cover type mapping results. ERDC-EL developed a series of protocols to calculate these parameters and incorporated their resultant shapefiles into the study's geodatabase (Table 7).[1]

Hydrologic data

The hydrological information presented in Table 8 was generated by Steve Boberg and Ondrea Hummel in the Albuquerque District and provided to ERDC-EL in response to a request for assessment methodology and documentation. Any questions surrounding this information should be addressed to Hummel (refer to Appendix D for point of contact information).

[1] Contact Ondrea Hummel in the USACE Albuquerque District Office to obtain copies of the geodatabase.

Table 7. GIS sampling protocols summarized for the variables associated with the Bosque Riparian community index model.

Code	Variable Description	Sampling Methodology	Cover Type Applicability
DISTPATCH	Distance to Nearest Patch (aka Nearest Neighbor of Forest or Meadow) (m)	To calculate the distance between like patches (NEIGHBOR), a tool developed by Jeff Lin at ERDC-EL was employed (http://el.erdc.usace.army.mil/emrrp/gis.html). Step 1: Build Base files using the Individual Cover Type (dissolved) *PATCHSIZE* files developed earlier - merge these to make one Cover Type file containing all the like polygons across the five reaches. . . these will be used to calculate nearest neighbor for the baseline condition in Step 4 below. Step 2: Create 10 template files (1 per Cover Type) for each reach, by systematically clipping out each reach from the Base files (i.e., Template for Reach 1's Type_1 has all Type_1 polygons for Reach 2-5, but lacks Reach 1's). Step 3: For each alternative, merge the WP Type files from the Dissolved *PATCHSIZE* files with the Template files (10 files per alternative - 1 for each TYPE will all Reach polygons included). Step 4: Run the NearestNeighbor.py script on each file. Step 5: Export the data from this analysis into Excel using Xtools Pro (or from the table view). Step 6: Clip out non-applicable reaches (i.e., for Plan 1-A, only use the nearest neighbor calculations for Reach 1 polygons). Step 7: Convert the nearest neighbor values from feet to meters, and average the values across the Reach for each Cover Type. To characterize/quantify changes in WOP and WP conditions based on successional trends, a "factor" was applied to the *PATCHSIZE* variables over the course of the remaining TYs to show change over time. The variable was calculated at the Landscape scale (i.e., Type 1 and New Type 1 cover types were combined as a single class for this exercise).	ALL TYPES
PATCHSIZE	Size of Patch (ac)	Step 1: Select by attribute the target cover type and export it as a separate shape file for that cover type. Step 2: Using the Dissolve tool, edit the file, and select all target features (this must be done at the Reach level - i.e., dissolve on Reach ID). Step 3: Explode these (using the explode multipart feature tool) to ensure that multiple, separate polygons aren't being misrepresented by what appears as a single feature in the attribute table, which is in reality a merged multipart feature. Step 4: Recalculate the acres after this step (using Xtools pro or the VBA code for calculating area while in editor). Step 5: Export the data as a database file from the attribute table view or into Excel using Xtools Pro. Step 6: Patch size for bosque cover types were calculated by reach by dividing the total area of these cover types by the number of patches (polygons) within each reach.	ALL TYPES

Code	Variable Description	Sampling Methodology	Cover Type Applicability
		To characterize/quantify changes in WOP and WP conditions based on successional trends, a "factor" was applied to the *PATCHSIZE* variables over the course of the remaining TYs to show change over time. The variable was calculated at the Landscape scale (i.e., Type 1 and New Type 1 cover types were combined as a single class for this exercise). All polygons smaller than 0.05 acres were merged with the nearest polygon using ArcGIS's "Eliminate" tool.	
TYPDISTURB	Type of Human Disturbance (aka Adjacent Landuse Within 2 km)	Step 1: Open the individual Reach shapefiles and use the ArcGIS Buffer Wizard to draw 2-km buffers around each Reach Step 2: Merge these buffer files, and clip the Land Use/Land Cover (LULC) file (to reduce processing) Step 3: Reclassify the Clipped LULC file based on the five Disturbance Types (1 Commercial/Industrial, 2 Residential, 3 Right of Ways and Railroads, 4 Agricultural Crops and Pastures, 5 Pristine, uninhabited areas) Step 4: Add two fields, one for the HEP Code and the HEP Description of these Disturbance types Step 5: X-walk the LULC descriptions and the HEP descriptions/codes (either in *.xls or using expression files and attribute selection) Step 6: Eliminate any "unknown" polygons, and recalculate the area of the shapefile (using XTools) Step 7: Open the 10-1-7 Reach Map, select the area under the reach, use the calculator to reclassify all these areas as "natural" category 5 Step 8: Erase file from Step 6 with file from Step 7 Step 9: Merge file from Step 8 with file from Step 7, Add a field called "Reach" Step 10: Clip the Step 9 file with the individual reach buffer files in Step 1, and fill in the Reach number with the Calculator Step 11: Recalculate the area and export to Excel (using XTools) Step 12: Sum the acres by category and determine the category with the most acres (proportionately) To characterize/quantify changes in WOP and WP conditions, assume that residential/commercial would remain, and that 10% of the agricultural croplands would be lost to development each target year. The variable was calculated at the Landscape scale at the Reach level (i.e., all types in the reach are assigned the same value).	ALL TYPES

Table 8. Hydrologic data sampling protocols summarized for the variables associated with the Bosque Riparian community index model.

Code	Variable Description	Sampling Methodology	Cover Type Applicability
DEPTHGW	Depth to Groundwater (ft)	Depth to groundwater was taken at each reference site if a well was within that patch. If a well was not within that patch, the nearest known well was used. Data were obtained for the date closest to the field sampling date from wells being monitored by the Corps, U.S. Forest Service, and BEMP (Bosque Ecosystem Monitoring Program).	ALL TYPES
DURATION	Average Duration of Flooding Events (days)	Flood duration defines the amount of time that a specific flood frequency will meet or exceed a given discharge or flow rate. Flood duration is typically defined in either hours or days. For this study the flood duration is defined as the number of days a specific flood frequency exceeds 3,000 cfs. The flood durations for the three flood frequencies considered for this study are as follows: Discharge Flood Frequency # days > 3,000 cfs 21 day duration flow** 3,770 cfs 70% 30 days 3500, cfs 6,500 cfs 31% 51 days 5460 cfs 10,000 cfs 4% 65 days 8230 cfs	ALL TYPES
FLOODFREQ	Frequency of Flooding (#/yr)	Flood frequency relates the magnitude of discharge to the probability of occurrence or exceedance. Discharge or flow rate is typically given in cubic feet per second (cfs). Probability is given as the likelihood of a particular event occurring in a given year. Therefore, the event commonly called "the 100 year storm" is given a flood frequency of 0.01 or 1% since that is the likelihood that it will occur in any given year. The flood frequencies being considered for this study are as follows: Discharge Flood Frequency Return Period Comment 3,770 cfs 70% 1.42 years Average Annual Hydrograph 6,500 cfs 31% 3.25 years Bank Full Hydrograph 10,000 cfs 4% 23.6 years Future Target Release	ALL TYPES
WETTEDAREA	Percent of Polygon That Is Wet (%)	The wetted area is defined as that area in the Bosque located between the active channel bankline and the levee that is inundated during flooding events. This area is known as the overbank and is the area where the inventoried sites are located. For any given reach of the Rio Grande there are two overbank areas, the left over-bank (LOB) and the right overbank (ROB) defined from looking downstream. For this project the LOB is on east side of the Rio Grande and the ROB is on the west side of the Rio Grande. The wetted area is that area of the overbank that would be flooded from "over-banking" of active channel flows in the Rio Grande during a given flood frequency. The Wetted Area for the individual inventoried sites will be given in percent of area within the site that is inundated or wetted. The wetted areas were determined primarily by the use of the FLO-2D hydraulic model and verified by the HEC-RAS hydraulic model. In some areas of the Corrales reach, the HEC-RAS hydraulic model only was used since this area was outside of the FLO-2D analysis limits.	ALL TYPES

HSI statistical analysis and curve calibrations

The reference condition described earlier defined the measurement scale and the state toward which the E-Team desired to move the system. In the case of the MRGBER project, the reference-based approach employed “reference standard ecosystems” to establish optimal conditions (HSI = 1.0) that served as benchmarks or standards of comparison for the existing and future conditions. Locating “degraded” reference sites was essential to calibrating the model. These “degraded” reference conditions represented the other end of the measurement scale and represented the ecological systems that were clearly degraded and socially unacceptable (HSI – 0.0). This process is referred to as “calibration,” which is defined here loosely as the use of known (reference) data on the observed relationship between a dependent variable and an independent variable to estimate other values of the independent variable from new observations of the dependent variable.

The models were calibrated by using the average values across the watershed and their associated standard deviations to generate a curve for each variable in each model. These statistics were calculated on both a “cover type-by-cover type” basis, as well as at the broader reach and watershed scales. To develop curves for each variable, ERDC used a straightforward assignment process. The watershed mean was assigned a 0.75 SI value in every case. The standard deviation of the mean was added to the average, and this total was assigned a 1.0 SI on the curve (Figure 42).

In most instances, the E-Team made the decision to calibrate the curve on the basis of cover type distinctions. For example, the E-Team reviewed the individual cover type means and made the decision that TYPE 1 and TYPE 3 cover types have significantly lower levels of herbaceous canopy cover than the rest of the watershed’s cover types. As a result, they chose to create two curves - one for each unique setting (Figure 43).

Ultimately, the curves developed for the watershed were the result of an iterative process where the E-Team directed ERDC-EL to gradually modify the curves to better reflect reality as they perceived it “in the field.” ERDC-EL made a conscious effort to fully document these changes, and curves that have been altered from the means and standard deviations as a result of “expert judgment” are presented as “red” curves in the graphs and supporting text (Figure 44).

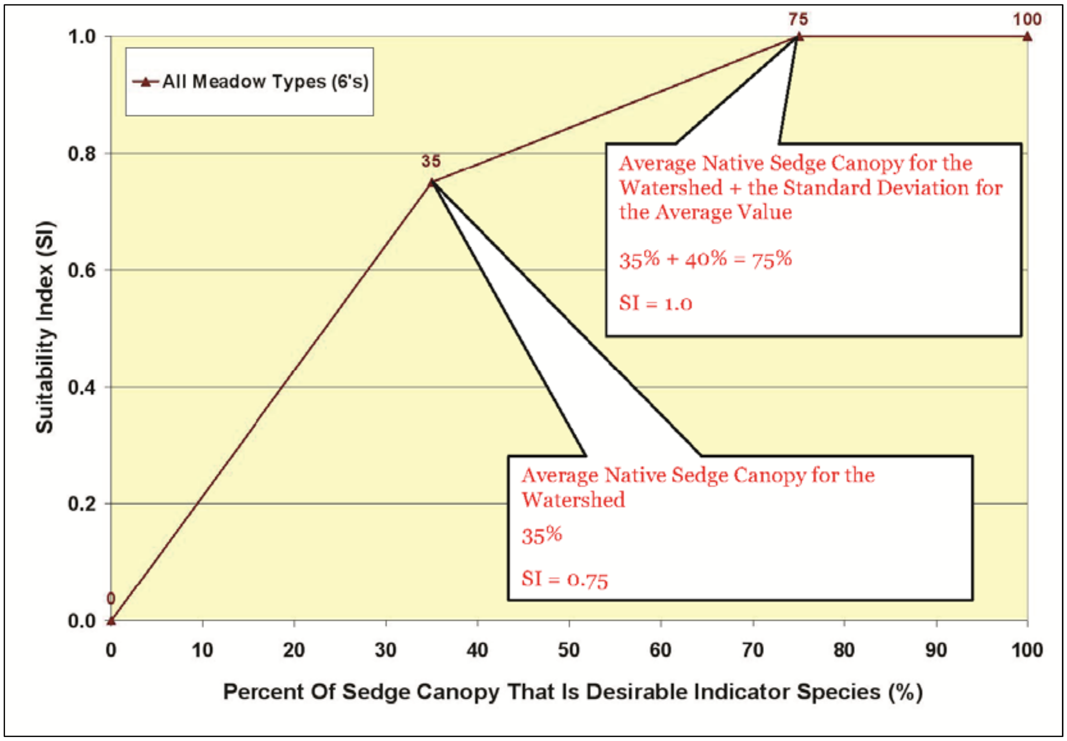


Figure 42. Example of curve calibration method using the reference mean and its standard deviation.

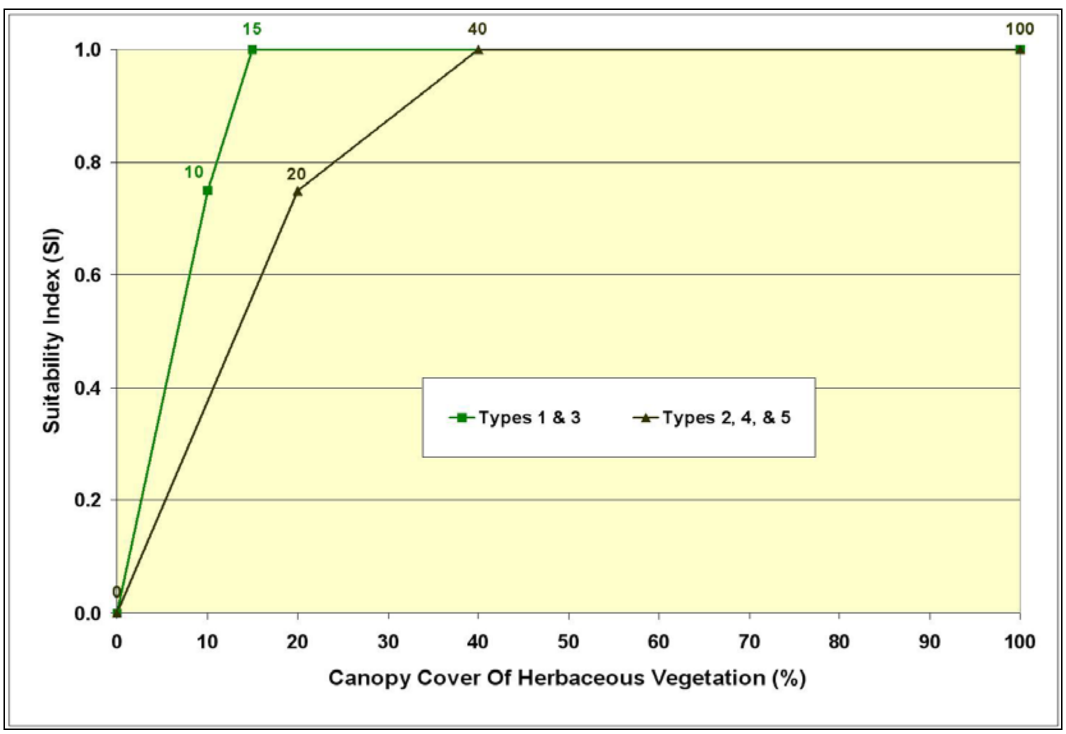


Figure 43. The model calibration approach was flexible enough to encourage and incorporate professional expertise into the methodology. Here, the reference data support the separation of cover types based on mean data. Type 1 and 3 classes have significantly higher tree canopy cover, shading out the herbaceous layers closer to the ground. As a result, the HSI model was calibrated to capture this unique feature.

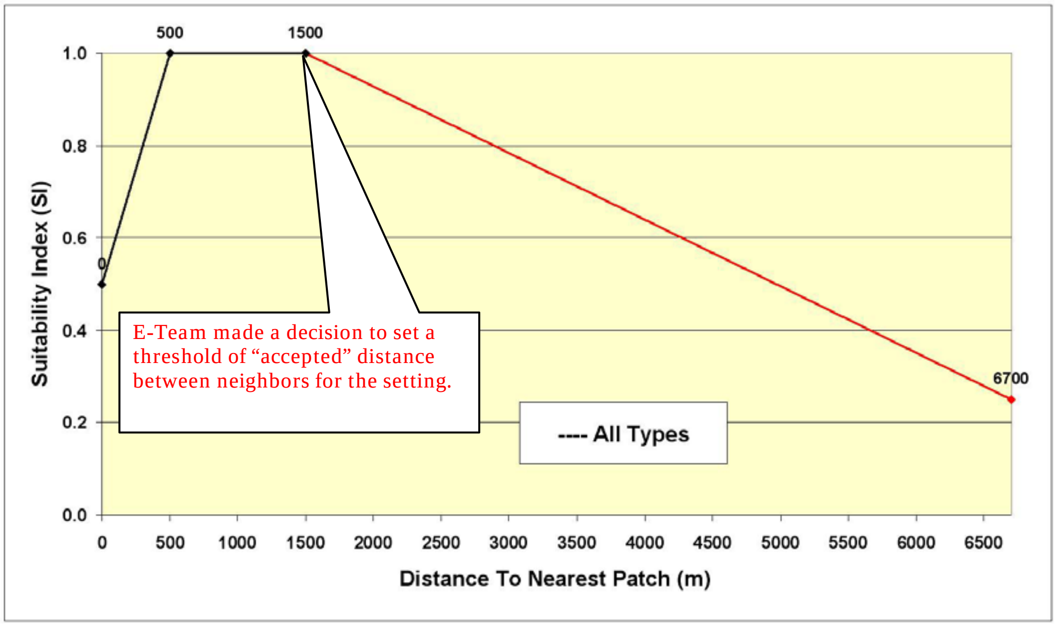


Figure 44. Example of curve calibration method using a combination of watershed means, standard deviations, and expert opinion.

To review the final curves for the Bosque Riparian HSI model, refer to Appendix E.

Model results

Because the community-based index model for Middle Rio Grande bosque was developed to operate on a larger, watershed scale, it was important to test the veracity of the tool at the reach level[1] (Figure 45).

To do this, the individual reference site field data collected between 2005 and 2008 were compiled on a reach-by-reach basis. Data for each variable per cover type within the community were recorded and the variable means/modes were calculated to generate watershed baseline HSIs at the reach level.[2] Twenty-three variables were measured according to the sampling protocols described above at the reference sites for the bosque community. The means for each variable are summarized in Table 9.

1 Testing here refers to model verification or "the act of reviewing, inspecting, testing, etc. to establish and document that a product, service, or system meets the regulatory, standard, or specification requirements."

2 GIS shapefiles and associated datasets are available upon request - contact the District POC (Ondrea Hummel, contact information can be found in *Appendix D*).

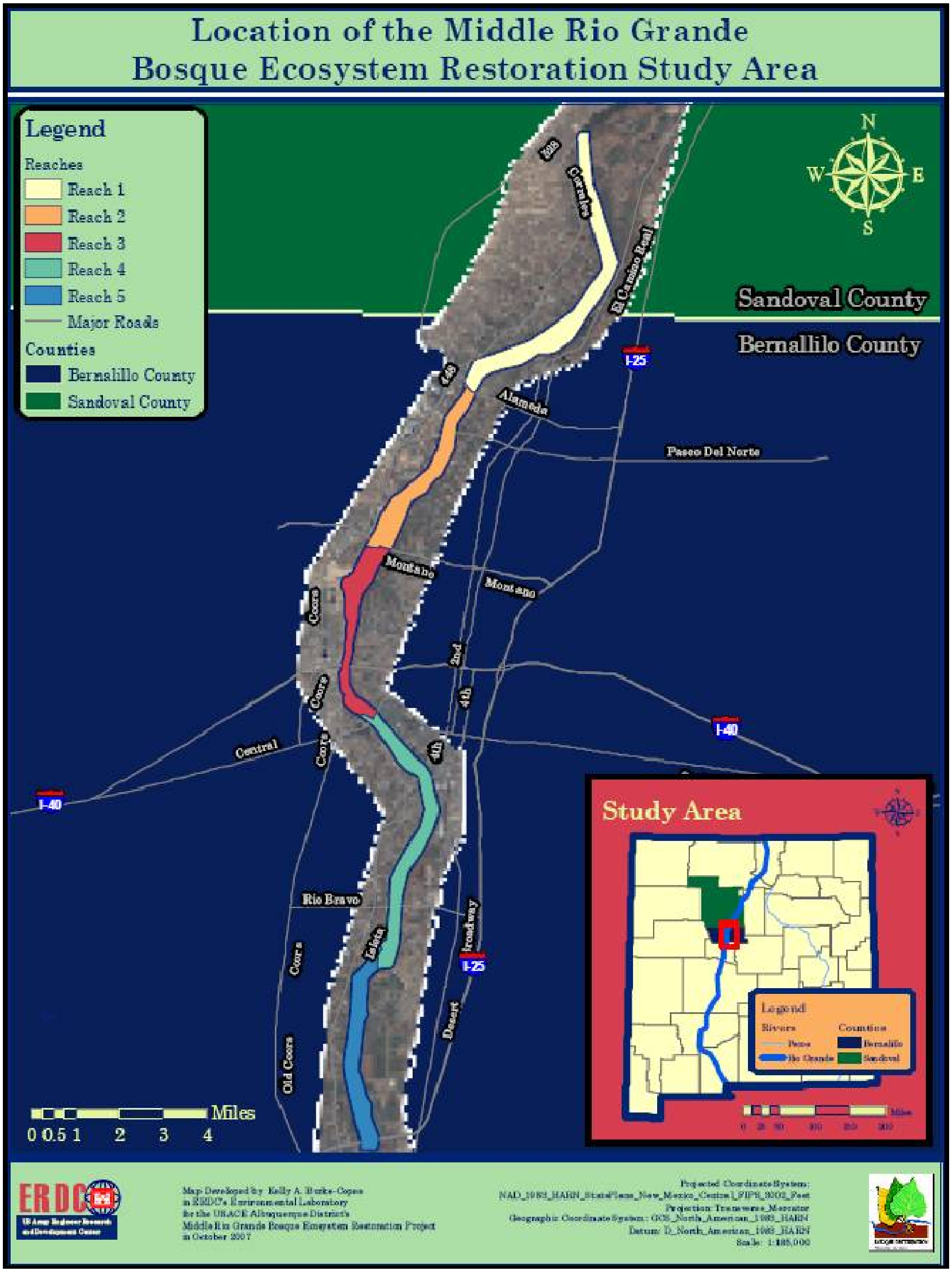


Figure 45. Reaches delineated for the baseline HSI assessment of the MRGBER study.

Table 9. Baseline data for the five reaches used to verify the Bosque Riparian HSI model.

Reach	Cover Type	BASALAREA	CANFORB	CANGRASS	CANHERB	CANSEDGE	CANSHRUB	CANTREE	COVGRND	CTGRNDCOV	DEPTHGW	DEPTHOM	DISTBIGTR	DISTPATCH	DURATION	FLOODFREQ	INDICATFB	INDICATGR	INDICATHB	NATIVESDG	NATIVETREE	PATCHSIZE	SPPCOUNT	TYPDISTURB	TYPEPATCH	WETTEDAREA
1	1	45			15		10	90	95	1	6.0	4.5	6.5	190	0	0			15		80	20.5	5	6	2	0
	2T	20			25		0	90	95	1	3.5	3.5	8.5	15	0	0			40		95	18.0	7	2	2	0
	2U	20			50		0	90	100	1	6.0	2.5	5.0	0	0	0			20		70	24.5	5	7	2	0
	3	45			20		10	65	100	1	5.5	7.0	11.0	555	0	0			15		35	11.5	3	4	2	0
	4T	20			40		0	65	80	1	7.0	2.0	14.0	75	0	0			10		90	17.0	7	6	2	0
	4U	25			15		10	35	65	1	7.5	1.5	8.5	770	0	0			0		60	5.0	3	6	2	0
	5	35			30		15	30	90	1	4.5	2.5	14.0	25	0	0			40		15	3.5	5	6	2	0
	6T		15	20		0	5				5.0			150	0	0	20	35		0		10.0	5	5	2	0
	6U		0	10		0	30				6.0			105	0	0	0	0		0		8.0	5	4	2	0
	6W		25	15		20	50				6.5			315	20	1	0	0		60		5.0	4	8	2	100
2	1	65			0		35	85	80	1	8.0	3.5	7.5	535	0	0			0		100	6.0	3	4	2	0
	2T	30			55		0	100	95	1	3.5	3.5	8.0	50	0	0			45		95	19.0	12	2	2	0
	2U	35			20		0	90	95	1	4.5	3.5	6.5	115	0	0			5		65	18.0	4	6	2	0
	3	65			10		5	80	95	1	8.5	3.5	8.5	345	0	0			30		40	5.0	3	4	2	0
	4T	20			35		0	50	60	1	9.0	2.0	16.5	60	0	0			5		95	16.0	7	5	2	0
	4U	30			20		5	35	70	1	6.0	1.5	9.0	545	0	0			0		60	10.0	3	6	2	0
	5	35			30		15	30	90	1	4.5	2.5	14.0	25	0	0			40		15	3.5	5	6	2	0
	6T		15	20		0	5				5.0			150	0	0	20	35		0		10.0	5	5	2	0

Reach	Cover Type	BASALAREA	CANFORB	CANGRASS	CANHERB	CANSEDGE	CANSHRUB	CANTREE	COVGRND	CTGRNDCOV	DEPTHGW	DEPTHOM	DISTBIGTR	DISTPATCH	DURATION	FLOODFREQ	INDICATFB	INDICATGR	INDICATHB	NATIVESDG	NATIVETREE	PATCHSIZE	SPPCOUNT	TYPDISTURB	TYPEPATCH	WETTEDAREA
	6U		5	15		5	45				4.5			135	0	0	0	0		60		5.5	5	5	2	0
	6W		20	10		20	35				6.0			210	15	0	0	0		40		11.5	3	8	2	65
3	1	35			30		0	95	100	1	5.5	3.5	6.0	0	0	0			0		45	30.5	5	8	2	0
	2T	10			0		0	90	100	1	2.0	5.0	8.5	0	0	0			0		85	23.5	5	1	2	0
	2U	35			15		0	85	90	1	3.5	3.5	6.0	235	0	0			0		50	15.0	4	6	2	0
	3	50			10		10	65	100	1	5.5	7.0	11.0	555	0	0			15		35	11.5	3	4	2	0
	4T	15			65		0	75	90	1	5.5	2.0	11.0	165	0	0			10		100	16.5	5	8	2	0
	4U	30			20		5	35	70	1	6.0	1.5	9.0	545	0	0			0		60	10.0	3	6	2	0
	5	25			30		10	10	100	1	2.5	5.0	16.5	0	0	0			65		0	3.0	8	6	2	0
	6T		15	20		0	5				5.0			150	0	0	20	35		0		10.0	5	5	2	0
	6U		5	15		5	45				4.5			135	0	0	0	0		60		5.5	5	5	2	0
	6W		15	5		25	5				5.0			0	0	0	0	0		0		23.5	2	7	2	0
4	1	45			15		10	90	95	1	6.0	4.5	6.5	190	0	0			15		80	20.5	5	6	2	0
	2T	20			25		0	90	95	1	3.5	3.5	8.5	15	0	0			40		95	18.0	7	2	2	0
	2U	50			0		0	100	100	1	4.0	4.0	8.0	0	0	0			0		90	19.5	5	4	2	0
	3	45			10		10	65	100	1	5.5	7.0	11.0	555	0	0			15		35	11.5	3	4	2	0
	4T	25			25		0	65	90	1	7.0	2.0	14.5	0	0	0			15		80	18.5	8	4	2	0
	4U	45			30		0	40	85	1	6.0	1.5	9.0	545	0	0			5		70	18.5	3	7	2	0

Reach	Cover Type	BASALAREA	CANFORB	CANGRASS	CANHERB	CANSEDGE	CANSHRUB	CANTREE	COVGRND	CTGRNDCOV	DEPTHGW	DEPTHOM	DISTBIGTR	DISTPATCH	DURATION	FLOODFREQ	INDICATFB	INDICATGR	INDICATHB	NATIVESDG	NATIVETREE	PATCHSIZE	SPPCOUNT	TYPDISTURB	TYPEPATCH	WETTEDAREA
	5	35			30		15	30	90	1	4.5	2.5	14.0	25	0	0			40		15	3.5	5	6	2	0
	6T		15	20		0	5				5.0			150	0	0	20	35		0		10.0	5	5	2	0
	6U		15	35		10	70				6.0			105	0	0	0	5		85		4.0	4	4	2	0
	6W		20	10		20	35				6.0			210	15	0	0	0		40		11.5	3	8	2	65
5	1	40			10		0	95	100	1	5.0	6.5	5.5	35	0	0			50		90	25.5	8	7	2	0
	2T	15			20		0	80	95	1	5.5	2.5	9.5	0	0	0			80		100	11.5	3	4	2	0
	2U	35			20		0	90	95	1	4.5	3.5	6.5	115	0	0			5		65	18.0	4	6	2	0
	3	30			0		0	100	100	1	5.5	14.5	7.5	1530	0	0			0		60	30.5	3	7	2	0
	4T	20			40		0	65	80	1	7.0	2.0	14.0	75	0	0			10		90	17.0	7	6	2	0
	4U	30			20		5	35	70	1	6.0	1.5	9.0	545	0	0			0		60	10.0	3	6	2	0
	5	40			30		20	45	90	1	5.5	1.5	13.0	40	0	0			25		25	5.0	4	6	2	0
	6T		15	20		0	5				5.0			150	0	0	20	35		0		10.0	5	5	2	0
	6U		0	0		0	35				1.5			190	0	0	0	0		100		4.5	5	8	2	0
	6W		20	10		20	35				6.0			210	15	0	0	0		40		11.5	3	8	2	65

Note: Blank cells indicate the variable was not associated with the particular cover type and therefore was not sampled therein.

The results of the baseline HEP assessment for the reaches are summarized below. HSIs capture the quality of the acreage within the reach. Units (i.e., HUs) take this quality and apply it to the governing area through multiplication (Quality X Quantity = Units). Both HSIs and HUs are reported for each reach. Interpretations of these findings are provided in Table 10.

Table 10. Interpretation of HSI scores resulting from HEP assessments.

HSI Score	Interpretation
0.0	Not-suitable - the community does not perform to a measurable level and will not recover through natural processes
Above 0.0 to 0.19	Extremely low or very poor functionality (i.e., habitat suitability) - the community functionality can be measured, but it cannot be recovered through natural processes
0.2 to 0 .29	Low or poor functionality
0.3 to 0.39	Fair to moderately low functionality
0.4 to 0 .49	Moderate functionality
0.5 to 0.59	Moderately high functionality
0.6 to .79	High or good functionality
0.8 to0.99	Very high or excellent functionality
1.0	Optimum functionality - the community performs functions at the highest level - the same level as reference standard settings

In most instances, the individual component indices (aka Life Requisite Suitability Indices or LRSIs) and composite HSIs scored in the mid-range of values (<0.5) indicating only a moderate level of functionality in the study area (Table 11 and Figure 46).[1] The highest functioning reach was Reach 1 (HSI = 0.50). This was to be expected – the last vestiges of undisturbed bosque are found in this area. Not surprisingly, Reaches 2 and 3 generated the lowest HSI scores (HSIs ranged from 0.40 to 0.41). Located in the heart of Albuquerque, these areas are highly urbanized and experience extreme levels of disturbance and invasive encroachment. These areas were also targeted for moderate to heavy fire prevention, and as such, their understories had incurred significant impacts.

Comparing the proposed restoration initiatives to "virtual" reference conditions (HSI = 1.0), the reaches are functioning at approximately 40 to 50 percent of the maximum potential. Clearly, there are opportunities for

[1] Data are available upon request - contact the District POC (Ondrea Hummel, contact information can be found in Appendix D).

improvements – in other words, all the reaches are prime candidates for restoration/rehabilitation activities in terms of the bosque community's structure and functionality.

Table 11. Baseline tabular results for the bosque riparian community.

Reach Name	LRSI Code	LRSI Score	Habitat Suitability Index (HSI)	Applicable Acres	Baseline Habitat Units (HUs)
Reach 1	RIP-BIOINTEG	0.41	0.50	1090	541
	RIP-SPATIAL	0.76			
	RIP-HYDRO	0.32			
Reach 2	RIP-BIOINTEG	0.39	0.40	561	225
	RIP-SPATIAL	0.54			
	RIP-HYDRO	0.28			
Reach 3	RIP-BIOINTEG	0.38	0.41	502	206
	RIP-SPATIAL	0.59			
	RIP-HYDRO	0.26			
Reach 4	RIP-BIOINTEG	0.41	0.42	726	307
	RIP-SPATIAL	0.53			
	RIP-HYDRO	0.33			
Reach 5	RIP-BIOINTEG	0.37	0.48	616	296
	RIP-SPATIAL	0.75			
	RIP-HYDRO	0.33			

Model verification

The first test of the model was to assess the various reference sites (both optimal and sub-optimal) with the formulas and curves and determine whether the model was "relating to reality" with respect to the E-Team's expectations. This step is considered to be model verification:

> ***Verification*** *(aka Confirmation) is the comparison of the model output to data from well-known, published test cases to confirm that the algorithms and computer code accurately represent system dynamics.* [1]

[1] Personal communication regarding American Society of Civil Engineers' definitions with Dr. John Nestler, ERDC-EL, August 2009.

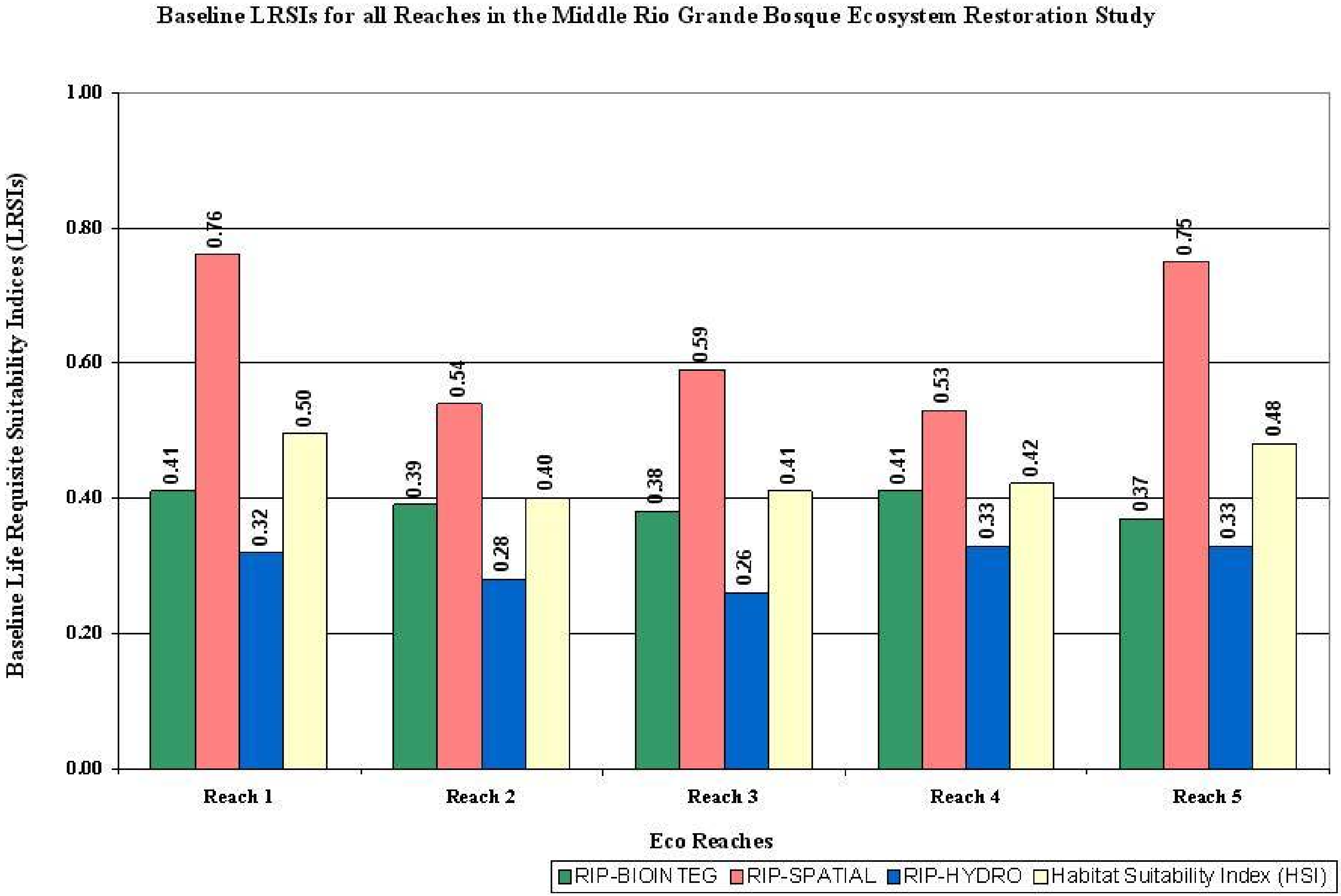


Figure 46. Baseline graphical results for the bosque community.

For purposes of this effort, *verification* asks whether the model is responding as the experts believe it should. Sites deemed to be highly functional wetlands according to experts should produce high HSI scores. Sites deemed dysfunctional (by the experts) should produce low HSI scores. Again, the model calibration effort described above was an iterative process, and as such, changes to the model's curves and algorithms were made in an attempt to bring these results as close to the expected outcome as possible. Admittedly, this process was somewhat subjective. But the experts working on the process were the best in the region, and where possible, actual reference conditions and/or historical data sets and literature-based studies were used to refine the model throughout the process. Both the E-Team's expectation of reference site condition (i.e., **High**, **Medium**, or **Low**), and the results of the final iteration of model calibration are presented in Tables 12 and 13.

A simple test of the veracity of the models and the expert's opinions of the reference site conditions was performed using a correlation analysis (Figure 47).

The most common measure of correlation is the Pearson Product Moment Correlation (aka Pearson's correlation).[1] The Pearson correlation values range from +1 to -1. A rule-of-thumb interpretation of the Pearson's correlation is found in the corner of Figure 47. This analysis demonstrates that the model is moderately correlated to expert opinion regarding site conditions, and therefore can be said to pass the test of "verification" (Pearson correlation value = 0.31). Because the area is suffering from severe alterations of the natural hydrologic regime, and there are no sites within the reference domain functioning at the expected optimal levels, the E-Team felt it was still reasonable to assume that the model offered a solid, scientifically driven means to characterizing conditions and assessing alternative plans. So for now, the E-Team has agreed that the reference sites were functioning at a reasonable level of expectation and as such the model calibrations were deemed acceptable.

[1] Background information was retrieved from http://en.wikipedia.org/wiki/Pearson_product-moment_correlation_coefficient and http://davidmlane.com/hyperstat/A34739.html (September 2008).

Table 12. Baseline results for the Bosque Riparian HSI assessment of the reference sites.

Reach	Reference Site	Site No.	Cover Type	Model Components			Habitat Suitability Index (HSI)
				RIP-BIOINTEG	RIP-SPATIAL	RIP-HYDRO	
Reach 1	Corrales	28	TYPE_2U	0.32	0.00	0.00	0.11
	Corrales	29	TYPE_6W	0.64	0.68	0.91	0.74
	Corrales	30	TYPE_6W	0.48	0.00	0.75	0.41
	Corrales	33	TYPE_4U	0.34	0.30	0.00	0.21
	Alameda	34	TYPE_4U	0.41	0.29	0.00	0.23
	Alameda NE	36	TYPE_6U	0.24	0.21	0.00	0.15
Reach 2	Paseo NE	1	TYPE_1	0.48	0.23	0.00	0.24
	Paseo NE	2	TYPE_3	0.41	0.23	0.00	0.21
	Paseo NE	3	TYPE_6T	0.19	0.12	0.00	0.10
	Paseo SE	4	TYPE_4T	0.29	0.31	0.00	0.20
	Paseo SE	5	TYPE_3	0.23	0.28	0.00	0.17
	Paseo SW	6	TYPE_2T	0.34	0.19	0.00	0.18
	La Orilla N	7	TYPE_6T	0.34	0.45	0.00	0.26
	La Orilla S	8	TYPE_6T	0.19	0.00	0.00	0.06
Reach 3	Oxbow N	9	TYPE_5	0.43	0.00	0.00	0.14
	Oxbow M	10	TYPE_6W	0.21	0.00	0.00	0.07
	Oxbow S	11	TYPE_2U	0.26	0.16	0.00	0.14
	RGNC N	12	TYPE_2U	0.41	0.00	0.00	0.14
	RGNC S	13	TYPE_4T	0.47	0.75	0.00	0.40
	RGNC W	14	TYPE_1	0.36	0.00	0.00	0.12
	Montano SW	15	TYPE_2T	0.31	0.00	0.00	0.10
Reach 4	Bridge SW	16	TYPE_4T	0.44	0.00	0.00	0.15
	AOP	17	TYPE_2U	0.32	0.00	0.00	0.11
	Rio Bravo NE	18	TYPE_4U	0.45	0.52	0.00	0.32
	Tingley Bar	35	TYPE_6U	0.66	0.15	0.00	0.27
Reach 5	Harrison levee	20	TYPE_1	0.37	0.00	0.00	0.12
	Harrison bar	21	TYPE_6U	0.18	0.47	0.00	0.22
	SDC North levee	22	TYPE_2T	0.23	0.00	0.00	0.08
	SDC North river	23	TYPE_5	0.45	0.00	0.00	0.15
	SDC South	24	TYPE_5	0.35	0.25	0.00	0.20
	Price's Dairy	26	TYPE_3	0.36	0.71	0.00	0.36

Table 13. Comparison of the baseline reference results to the E-Team's expectation of reference conditions.

Reach	Reference Site	Site No.	Cover Type	Model Components: RIP-BIOINTEG	Model Components: RIP-SPATIAL	Model Components: RIP-HYDRO	Habitat Suitability Index (HSI)	Expected Value (E-Team Estimated)
Reach 1	Corrales	28	TYPE_2U	Low	Low	Low	Low	High
	Corrales	29	TYPE_6W	High	High	High	High	High
	Corrales	30	TYPE_6W	Medium	Low	High	Medium	High
	Corrales	33	TYPE_4U	Medium	Medium	Low	Low	Low
	Alameda	34	TYPE_4U	Medium	Medium	Low	Low	Medium
	Alameda NE	36	TYPE_6U	Low	Medium	Low	Low	Medium
Reach 2	Paseo NE	1	TYPE_1	Medium	Medium	Low	Low	High
	Paseo NE	2	TYPE_3	Medium	Medium	Low	Low	High
	Paseo NE	3	TYPE_6T	Low	Medium	Low	Low	Low
	Paseo SE	4	TYPE_4T	Low	Medium	Low	Low	Medium
	Paseo SE	5	TYPE_3	Low	Medium	Low	Low	Medium
	Paseo SW	6	TYPE_2T	Medium	Medium	Low	Low	Medium
	La Orilla N	7	TYPE_6T	Medium	Medium	Low	Low	Medium
	La Orilla S	8	TYPE_6T	Low	Low	Low	Low	Medium
Reach 3	Oxbow N	9	TYPE_5	Medium	Low	Low	Low	Low
	Oxbow M	10	TYPE_6W	Low	Low	Low	Low	Medium
	Oxbow S	11	TYPE_2U	Low	Medium	Low	Low	Medium
	RGNC N	12	TYPE_2U	Medium	Low	Low	Low	Medium
	RGNC S	13	TYPE_4T	Medium	High	Low	Medium	Medium
	RGNC W	14	TYPE_1	Medium	Low	Low	Low	Low
	Montano SW	15	TYPE_2T	Low	Low	Low	Low	Medium
Reach 4	Bridge SW	16	TYPE_4T	Medium	Low	Low	Low	Medium
	AOP	17	TYPE_2U	Low	Low	Low	Low	Medium
	Rio Bravo NE	18	TYPE_4U	Medium	Medium	Low	Low	Medium
	Tingley Bar	35	TYPE_6U	High	Medium	Low	Low	High
Reach 5	Harrison levee	20	TYPE_1	Medium	Low	Low	Low	Medium
	Harrison bar	21	TYPE_6U	Low	Medium	Low	Low	High
	SDC North levee	22	TYPE_2T	Low	Low	Low	Low	Low
	SDC North river	23	TYPE_5	Medium	Low	Low	Low	High
	SDC South	24	TYPE_5	Medium	Medium	Low	Low	Low
	Price's Dairy	26	TYPE_3	Medium	High	Low	Low	Medium

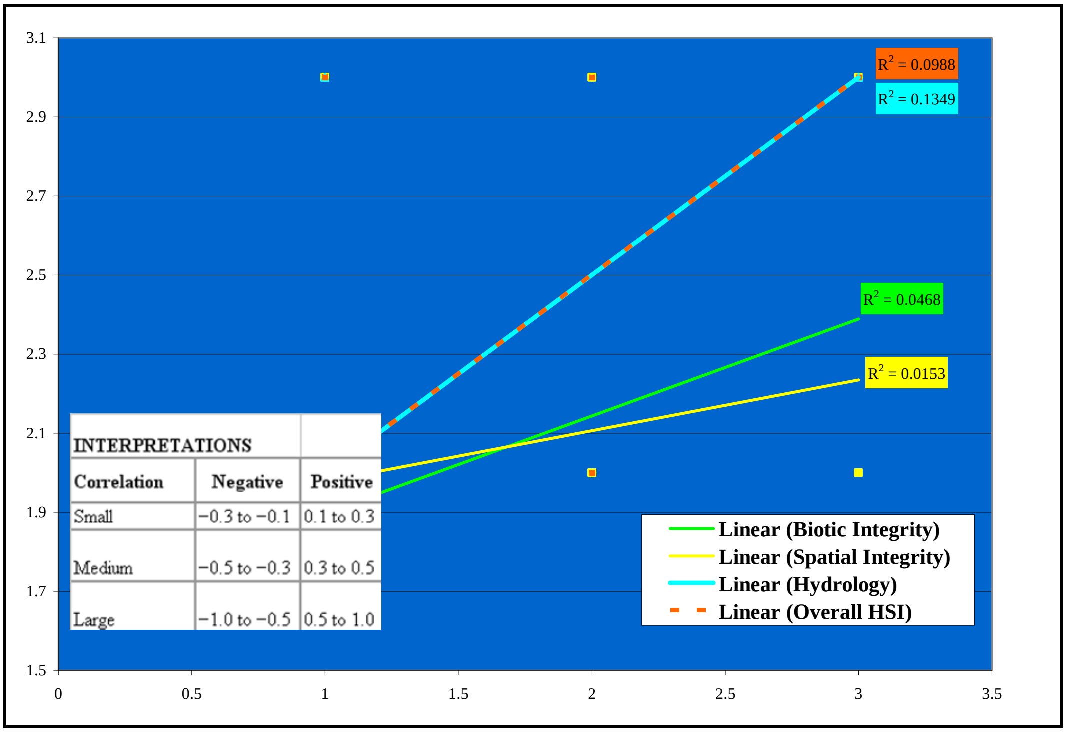


Figure 47. A Pearson's correlation of the expert team's opinion of site functionality and the HEP results indicate that they are positively related to some degree.

Model validation

To date, the Bosque (Riparian) community index model has not been validated. Model validation is defined here as:

> ***Validation*** *is accomplished by establishing an objective yet independent line of evidence that the model specifications conform to the user's needs and intended use(s). The validation process questions whether the model is an accurate representation of the system based on independent data not used to develop the model in the first place. Validation can encompass all of the information that can be verified, as well as all of the things that cannot -- i.e., all of the information that the model designers might never have anticipated the user might want or expect the product to do.* [1]

For purposes of this effort, *validation* refers to independent data collections (bird surveys, water quality surveys, etc.) that can be compared to the model outcomes to determine whether the model is capturing the

[1] Personal communication regarding American Society of Civil Engineers' definitions with Dr. John Nestler, ERDC-EL, August 2009.

essence of the ecosystem's functionality. As independent measures of function for the model herein, three options or directions to consider are proposed as future research opportunities:

1. A few "relevant" HSI Blue Book (species) models could be used to assess the baseline conditions of the area comparing their outputs to the community models' outputs. As these are already "approved" for use under the USACE model certification program, their outputs should provide relevant cross-validation. However, as most of the HSI Blue Books lack validation, this approach may not be appropriate either. And again, as the Blue Book models are designed to measure only limiting "life requisites" of these key species, they might not be inclusive enough to capture community function and processes.
2. An extremely expensive and time-consuming approach could be undertaken to assess biodiversity (both species richness and diversity) in an attempt to identify an "independent measure of function." However, to validate the communities modeled herein, a majority of the faunal groups present would need to be surveyed (mammals, birds, fish, reptiles, amphibians, plants, and possibly even insects). This in turn leads to the question, If we had time and funds to do this level of inventory, why use models at all?
3. Alternatively, the models could potentially be validated by assessing patch dynamics using a transition model at a landscape scale (Acevedo et al. 1995). Again, this would be validating models with models, which might not be considered a true validation exercise.

5 Summary and Conclusions

The implications of this report's findings are rather straightforward. First, the results support the conceptual premise surrounding the HSI model and indicate its representative capabilities. In other words, scientific literature characterizing the state of the bosque ecosystems along the middle Rio Grande point to an overall decline in ecosystem integrity (i.e., health, biodiversity, stability, sustainability, naturalness, wildness, and beauty) – a finding the model can now verify and quantify (less than optimal HSI scores were found in all reaches). Furthermore, the results indicate an opportunity to redress ongoing losses. There is great potential to restore sustainable bosque communities therein, offering a significant positive return on investment to both the stakeholders and the federal government.

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Appendix A: Notation

AAHU	Average Annual Habitat Unit
AOSD	City of Albuquerque Open Space Division
BOR	Bureau of Reclamation
CT	Cover Type
EA	Environmental Assessment
EC	Engineering Circular
ERDC-EL	Engineer Research and Development Center, Environmental Laboratory
ESM	Ecological Service Manual
E-Team	Ecosystem Assessment Team
EXHEP	EXpert Habitat Evaluation Procedures Module
EXHGM	EXpert Hydrogeomorphic Approach to Wetland Assessments Module
GIS	Geographic Information System
HEAT	Habitat Evaluation and Assessment Tools
HEP	Habitat Evaluation Procedures
HGM	Hydrogeomorphic Wetland Assessment
HSI	Habitat Suitability Index
HU	Habitat Unit
ISC	Interstate Stream Commission
IWR	Institute for Water Resources
LPDT	Laboratory-based Project Delivery Team
LRSI	Life Requisite Suitability Index
LTR	Laboratory-based Technical Review
LTRT	Laboratory-based Technical Review Team
LULC	Land Use/Land Cover
MCDA	Multi Criteria Decision Analysis
MRGBER	Middle Rio Grande Bosque Ecosystem Restoration Feasibility Study
MRGCD	Middle Rio Grande Conservancy District
NEPA	National Environmental Policy Act
NER	National Ecosystem Restoration Plan
NHNM	Natural Heritage New Mexico
NMDGF	New Mexico Department of Game and Fish
NMSFD	New Mexico State Forestry Division
NRC	National Research Council
PMIP	USACE Planning Models Improvement Program
RA	Relative Area
RMRS	Rocky Mountain Research Station
SERI	Society of Ecological Restoration International
SI	Suitability Index

SWCD	Ciudad Soil and Water Conservation District
TY	Target Year
UNM	University of New Mexico
USACE	U.S. Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency
USFS	U.S. Forest Service
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WOP	Without-project Condition
WP	With-project Condition

Appendix B: Glossary

Activity	The smallest component of a management measure that is typically a nonstructural, ongoing (continuing or periodic) action in USACE planning studies (Robinson et al. 1995).
Alternative (aka Alternative Plan, Plan, or Solution)	An alternative can be composed of numerous management measures that in turn are comprised of multiple features or activities. Alternatives are mutually exclusive, but management measures may or may not be combinable with other management measures or alternatives (Robinson et al. 1995). In HEP analyses, this is the "With-project" condition commonly used in restoration studies. Some examples of Alternatives include: *Alternative 1: Plant food plots, increase wetland acreage by 10 percent, install 10 goose nest boxes, and build a fence around the entire site.* *Alternative 2: Build a dam, inundate 10 acres of riparian corridor, build 50 miles of supporting levee, and remove all wetlands in the levee zone.* *Alternative 3: Reduce the grazing activities on the site by 50 percent, replant grasslands (10 acres), install a passive irrigation system, build 10 escape cover stands, use 5 miles of willow fascines along the stream bank for stabilization purposes.*
Assessment Model	A simple mathematical tool that defines the relationship between ecosystem/landscape scale variables and either functional capacity of a wetland or suitability of habitat for species and communities. Habitat Suitability Indices are examples of assessment models that the **HEAT** software can be used to assess impacts/benefits of alternatives.
Average Annual Habitat Units (AAHUs)	A quantitative result of annualizing Habitat Unit (HU) gains or losses across all years in the period of analysis. AAHUs = Cumulative HUs ÷ Number of years in the life of the project (aka period of analysis), where: Cumulative HUs = $\sum$ (T2 -T1)[{((A1 H1 +A2 H2) / 3)} +{((A2 H1 +A1 H2) / 6)}] and where: T1 = First Target Year time interval T2 = Second Target Year time interval A1 = Area of available wetland assessment area at beginning of T1 2 = Area of available wetland assessment area at end of T2 H1 = HSI at beginning of T1 H2 = HSI at end of T2.
Baseline Condition (aka Existing Conditions)	The point in time before proposed changes are implemented in habitat assessment and planning analyses. Baseline is synonymous with Target Year (TY = 0).

Blue Book	In the past, the USFWS was responsible for publishing documents identifying and describing HSI models for numerous species across the nation. Referred to as "Blue Books" in the field, due primarily to the light blue tint of their covers, these references fully illustrate and define habitat relationships and limiting factor criteria for individual species nationwide. Blue Books provide: HSI Models, life history characteristics, SI curves, methods of variable collection, and referential material that can be used in the application of the HSI model in the field. For copies of Blue Books, or a list of available Blue Books, contact your local USFWS office.
Calibration	The use of known (reference) data on the observed relationship between a dependent variable and an independent variable to estimate other values of the independent variable from new observations of the dependent variable.
Combined NED/NER Plan (Combined Plan)	Plans that produce both types of benefits such that no alternative plan or scale has a higher excess of NED plus NER benefits over total project costs (USACE 2003b).
Cover Type (CT)	Homogenous zones of similar vegetative species, geographic similarities and physical conditions that make the area unique. In general, cover types are defined on the basis of species recognition and dependence.
Ecosystem	A biotic community, together with its physical environment, considered as an integrated unit. Implied within this definition is the concept of a structural and functional whole, unified through life processes. Ecosystems are hierarchical, and can be viewed as nested sets of open systems in which physical, chemical and biological processes form interactive subsystems. Some ecosystems are microscopic, and the largest comprises the biosphere. Ecosystem restoration can be directed at different-sized ecosystems within the nested set, and many encompass multi-states, more localized watersheds or a smaller complex of aquatic habitat.
Ecosystem Assessment Team (E-Team)	An interdisciplinary group of regional and local scientists responsible for determining significant resources, identifying reference sites, constructing assessment models, defining reference standards, and calibrating assessment models. In some instances the E-Team is also referred to as the Environmental Assessment Team or simply the Assessment Team.
Ecosystem Function	Ecosystem functions are the dynamic attributes of ecosystems, including interactions among organisms and interactions between organisms and their environment (Society for Ecological Restoration International (SERI) 2004). Some restoration ecologists limit the use of the term "ecosystem functions" to those dynamic attributes that most directly affect metabolism, principally the sequestering and transformation of energy, nutrients, and moisture. Examples are carbon fixation by photosynthesis, trophic interactions, decomposition, and mineral nutrient cycling. When ecosystem functions are strictly defined in this manner, other dynamic attributes are distinguished as "ecosystem processes" such as substrate stabilization, microclimatic control, differentiation of habitat for specialized species, pollination, and seed dispersal. Functioning at larger spatial scales is generally conceived in more general terms, such as the long-term retention of nutrients and moisture and overall ecosystem sustainability.
Ecosystem Integrity	The state or condition of an ecosystem that displays the biodiversity characteristic of the reference, such as species composition and community structure, and is fully capable of sustaining normal ecosystem functioning (SERI 2004). These characteristics are often defined in terms such as health, biodiversity, stability, sustainability, naturalness, wildness, and beauty.

Ecosystem Services	The capacity of natural processes and components to provide goods and services that satisfy human needs directly or indirectly (de Groot et al. 2002). The benefits people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as regulation of floods, drought, land degradation, and disease; supporting services such as soil formation and nutrient cycling; and cultural services such as recreational, spiritual, religious, and other nonmaterial benefits (Millennium Ecosystem Assessment 2005).
Equivalent Optimal Area (EOA)	The concept of equivalent optimal area (EOA) is used in HEP applications where the composition of the landscape, in relation to providing life requisite habitat, is an important consideration. An EOA is used to weight the value of the LRSI score to compensate for this inter-relationship. For example, for optimal wood duck habitat conditions, at least 20% of an area should be composed of cover types providing brood-cover habitat (a life requisite). If an area has less than 20% in this habitat, the suitability is adjusted downward.
Existing Condition	Also referred to as the baseline condition, the existing condition is the point in time before proposed changes, and is designated as Target Year (TY = 0) in the analysis.
Feature	A feature is the smallest component of a management measure that is typically a structural element requiring construction in USACE planning studies (Robinson et al. 1995).
Field Data	This information is collected on various parameters (i.e., variables) in the field, and from aerial photos, following defined, well-documented methodology in typical HEP applications. An example is the measurement of percent herbaceous cover, over ten quadrats, within a cover type. The values recorded are each considered “field data.” Means of variables are applied to derive suitability indices and/or functional capacity indices.
Goal	A goal is defined as the end or final purpose. Goals provide the reason for a study rather than a reason to formulate alternative plans in USACE planning studies (Yoe and Orth 1996).
Guild	A group of functionally similar species with comparable habitat requirements whose members interact strongly with one another, but weakly with the remainder of the community. Often a species HSI model is selected to represent changes (impacts) to a guild.
Habitat Assessment	The process by which the suitability of a site to provide habitat for a community or species is measured. This approach measures habitat suitability using an assessment model to determine an HSI.
Habitat Suitability Index Model (HSI)	A quantitative estimate of suitability habitat for a site. The ideal goal of an HSI model is to quantify and produce an index that reflects functional capacity at the site. The results of an HSI analysis can be quantified on the basis of a standard 0-1.0 scale, where 0.00 represents low functional capacity for the wetland, and 1.0 represents high functional capacity for the wetland. An HSI model can be defined in words, or mathematical equations, that clearly describe the rules and assumptions necessary to combine functional capacity indices in a meaningful manner for the wetland.

Habitat Suitability Index Model (HSI) (cont)	For example: HSI = (SI V_1 * SI V_2) / 4, where: SI V_1 is the Variable Subindex for variable 1; SI V_2 is the SI for variable 2
Habitat Unit (HU)	A quantitative environmental assessment value, considered the biological currency in HEP. Habitat Units (HUs) are calculated by multiplying the area of available habitat (quantity) by the quality of the habitat for each species or community. Quality is determined by measuring limiting factors for the species (or community), and is represented by values derived from Habitat Suitability Indices (HSIs). HU = AREA (acres) X HSI. Changes in HUs represent potential impacts or improvements of proposed actions.
Life Requisite Suitability Index (LRSI)	A mathematical equation that reflects a species' or community's sensitivity to a change in a limiting life requisite component within the habitat type in HEP applications. LRSIs are depicted using scatter plots and bar charts (i.e., life requisite suitability curves). The LRSI value (Y axis) ranges on a scale from 0.0 to 1.0, where an LRSI = 0.0 means the factor is extremely limiting and an LRSI = 1.0 means the factor is in abundance (not limiting) in most instances.
Limiting Factor	A variable whose presence/absence directly restrains the existence of a species or community in a habitat in HEP applications. A deficiency of the limiting factor can reduce the quality of the habitat for the species or community, while an abundance of the limiting factor can indicate an optimum quality of habitat for the same species or community.
Locally Preferred Plan (LPP)	The name frequently given to a plan that is preferred by the non-Federal sponsor over the National Economic Development (NED) plan (USACE 2000).
Management Measure	The components of a plan that may or may not be separable actions that can be taken to affect environmental variables and produce environmental outputs. A management measure is typically made up of one or more features or activities at a particular site in USACE Planning studies (Robinson et al. 1995).
Measure	The act of physically sampling variables such as height, distance, percent, etc., and the methodology followed to gather variable information in HEP applications (i.e., see "Sampling Method" below).
Multiple Formula Model (MM) (aka Life Requisite Model)	In HEP applications, there are two types of HSI models, the Single Formula Model (SM) (refer to the definition below) and the Multiple Formula Model (MM). In this case a multiple formula model is, as one would expect, a model that uses more than one formula to assess the suitability of the habitat for a species or a community. If a species/community is limited by the existence of more than one life requisite (food, cover, water, etc.), and the quality of the site is dependent on a minimal level of each life requisite, then the model is considered an MM model. In order to calculate the HSI for any MM, one must derive the value of a Life Requisite Suitability Index (LRSI) (see definition below) for each life requisite in the model – a process requiring the user to calculate multiple LRSI formulas. This Multiple Formula processing has led to the name "Multiple Formula Model" in HEP.

Multi-Criteria Decision Analysis (MCDA)	The study of methods and procedures by which concerns about multiple conflicting criteria can be formally incorporated into the management planning process," as defined by the International Society on Multiple Criteria Decision Making (http://www.terry.uga.edu/mcdm/ MAY 2008). MCDA is also referred to as Multi-Criteria Decision Making (MCDM), Multi-Dimensions Decision-Making (MDDM), and Multi-Attributes Decision Making (MADM).
National Economic Development (NED) Plan	For all project purposes except ecosystem restoration, the alternative plan that reasonably maximizes net economics benefits consistent with protecting the Nation's environment, the NED plan, shall be selected. The Assistant Secretary of the Army for Civil Works (ASACW) may grant an exception when there are overriding reasons for selecting another plan based upon other Federal, State, local and international concerns (USACE 2000).
National Ecosystem Restoration (NER) Plan	For ecosystem restoration projects, a plan that reasonably maximizes ecosystem restoration benefits compared to costs, consistent with the Federal objective, shall be selected. The selected plan must be shown to be cost-effective and justified to achieve the desired level of output. This plan shall be identified as the National Ecosystem Restoration (NER) Plan (USACE 2000).
No Action Plan (aka No Action Alternative or Without-project Condition)	Also referred to as the Without-project condition, the No Action Plan describes the project area's future if there is no Federal action taken to solve the problem(s) at hand. Every alternative is compared to the same Without-project condition (Yoe and Orth 1996).
Objective	A statement of the intended purposes of the planning process; it is a statement of what an alternative plan should try to achieve. More specific than goals, a set of objectives will effectively constitute the mission statement of the Federal/non-Federal planning partnership. A planning objective is developed to capture the desired changes between the without- and with-project conditions that, when developed correctly, identify effect, subject, location, timing, and duration (Yoe and Orth 1996).
Plan (aka Alternative, Alternative Plan, or Solution)	A set of one or more management measures functioning together to address one or more planning objectives (Yoe and Orth 1996). Plans are evaluated at the site level with HEP or other assessment techniques and cost analyses in restoration studies (Robinson et al. 1995).
Program	Combinations of recommended plans from different sites make up a program. Where the recommended plan at each such site within a program is measured in the same units, a cost analysis can be applied in a programmatic evaluation (Robinson et al. 1995).
Project Area	The area that encompasses all activities related to an ongoing or proposed project.
Project Manager	Any biologist, economist, hydrologist, engineer, decision-maker, resource project manager, planner, environmental resource specialist, limnologist, etc., who is responsible for managing a study, program, or facility.
Reference Domain	The geographic area from which reference communities or wetlands are selected in HEP applications. A reference domain may, or may not, include the entire geographic area in which a community or wetland occurs.
Reference Ecosystems	All the sites that encompass the variability of all conditions within the region in HEP applications. Reference ecosystems are used to establish the range of conditions for construction and calibration of HSIs and to establish reference standards.

Reference Standard Ecosystems	The ecosystems that represent the highest level of habitat suitability or function found within the region for a given species or community in HEP applications.
Relative Area (RA)	The relative area is a mathematical process used to "weight" the various applicable cover types on the basis of quantity in HEP applications. To derive the relative area of a model's CTs, the following equation can be utilized: Relative Area = Acres of Cover Type / Total Applicable Area where: Acres of Cover Type = only those acres assigned to the cover type of interest within the site Total Applicable Area = the sum of the acres associated with the model at the site.
Relative Preferences	The rank of ecosystem services in order of importance. Relative preferences for various services are much easier to determine than differences in dollar measures of service values. Although less common than dollar measures of value, individual and community indices of ranked preferences can be used to aggregate service values and compare plans using a single measure (King et al. 2000).
Risk	The volatility of potential outcomes. In the case of ecosystem values, the important risk factors are those that affect the possibility of service flow disruptions and the reversibility of service flow disruptions. These are associated with controllable and uncontrollable on-site risk factors (e.g., invasive plants, overuse, or restoration failure) and landscape risk factors (e.g., changes in adjacent land uses, water diversions) (King et al. 2000).
Sampling Method	The protocol followed to collect and gather field data in HEP and HGM applications. It is important to document the relevant criteria limiting the collection methodology. For example, the time of data collection, the type of techniques used, and the details of gathering this data should be documented as much as possible. An example of a sampling method would be: *Between March and April, run five random 50-m transects through the relevant cover types. Every 10 m along the transect, place a 10-m^2 quadrat on the right side of the transect tape and record the percent herbaceous cover within the quadrat. Average the results per transect.*
Scale	In some geographical methodologies, the scale is the defined size of the image in terms of miles per inch, feet per inch, or pixels per acres. Scale can also refer to different "sizes" of plans (Yoe and Orth 1996) or variations of a management measure in cost analyses. Scales are mutually exclusive, and therefore a plan or alternative may only contain one scale of a given management measure (Robinson et al. 1995).
Single Formula Model (SM)	In habitat assessments, two potential types of models are selected to assess change at a site – the Single Formula Model and the Multiple Formula Model (refer to the definition above). In this instance, an HSI model is based on the existence of a single life requisite requirement, and a single formula is used to depict the relationship between quality and carrying capacity for the site.
Site	The location upon which the project manager will take action, evaluate alternatives, and focus cost analysis (Robinson et al. 1995).
Solutions (aka Alternative, Alternative Plan, or Plan)	A solution is a way to achieve all or part of one or more planning objectives (Yoe and Orth 1996). In cost analysis, this is the alternative (see definition above).

Spreadsheet	A type of computer file or page that allows the organization of data (alpha-numeric information) in a tabular format. Spreadsheets are often used to complete accounting/economic exercises.
Suitability Index (SI)	A mathematical equation that reflects a species' or community's sensitivity to a change in a limiting factor (i.e., variable) within the habitat type in HEP applications. These indices are depicted using scatter plots and bar charts (i.e., suitability curves). The SI value (Y-axis) ranges on a scale from 0.0 to 1.0, where an SI = 0.0 means the factor is extremely limiting, and an SI = 1.0 means the factor is in abundance (not limiting) for the species/community (in most instances).
Target Year (TY)	A unit of time measurement used in HEP that allows the project manager to anticipate and direct significant changes (in area or quality) within the project (or site). As a rule, the baseline TY is always TY = 0, where the baseline year is defined as a point in time before proposed changes would be implemented. As a second rule, there must always be a TY = 1, and a TY = X_2. TY_1 is the first year land- and water-use conditions are expected to deviate from baseline conditions. TY_{X2} designates the ending target year. A new target year must be assigned for each year the project manager intends to develop or evaluate change within the site or project. The habitat conditions (quality and quantity) described for each TY are the expected conditions at the end of that year. It is important to maintain the same target years in both the environmental and economic analyses.
Trade-offs(TOs)	Used to adjust the model outputs by considering human values. There are no right or proper answers, only acceptable ones. If trade-offs are used, outputs are no longer directly related to optimum habitat or wetland function (Robinson et al. 1995).
Validation	Establishing by objective, yet independent, evidence that the model specifications conform to the user's needs and intended use(s). The validation process questions whether the model is an accurate representation of the system based on independent data not used to develop the model in the first place. Validation can encompass all of the information that can be verified, as well as all of the things that cannot -- i.e., all of the information that the model designers might never have anticipated the user might want or expect the product to do. For purposes of this effort, *validation* refers to independent data collections (bird surveys, water quality surveys, etc.) that can be compared to the model outcomes to determine whether the model is capturing the essence of the ecosystem's functionality.
Variable	A measurable parameter that can be quantitatively described, with some degree of repeatability, using standard field sampling and mapping techniques. Often, the variable is a limiting factor for a wetland's functional capacity used in the development of SI curves and measured in the field (or from aerial photos) by personnel, to fulfill the requirements of field data collection in an HEP application. Some examples of variables include: height of grass, percent canopy cover, distance to water, number of snags, and average annual water temperature.
Verification	Model verification refers to a process by which the development team confirms by examination and/or provision of objective evidence that specified requirements of the model have been fulfilled with the intention of assuring that the model performs (Or behaves) as it was intended. Sites deemed to be highly functional wetlands according to experts, should produce high HSI scores. Sites deemed dysfunctional (by the experts) should produce low HSI scores.

Without-project Condition(WOP) (aka No Action Plan or No Action Alternative)	Often confused with the terms "Baseline Condition" and "Existing Condition," the Without-Project Condition is the expected condition of the site without implementation of an alternative over the life of the project (aka period of analysis), and is also referred to as the "No Action Plan" in traditional planning studies (Yoe and Orth 1996; USACE 2000).
With-project Condition (WP)	In planning studies, this term is used to characterize the condition of the site after an alternative is implemented (Yoe and Orth 1996, USACE 2000).

Appendix C: Model Certification Crosswalk

Information necessary to address model certification/one-time-use approval under EC 1105-2-407 is presented in *Table 2* of the *USACE Protocols for Certification of Planning Models* report (USACE 2007c, pages 9-11).[1] In an effort to streamline the review of the Bosque Riparian community-based (HSI) index model, the authors have provided a table to crosswalk the EC requirements and the information contained in this report (Table C1). One-time-use approval was granted by the Eco-PCX in April 2009, and the memo documenting this approval has been included below the table.

Table C1. Crosswalk between EC 1105-2-407 model certification requirements and information contained in this report.

Cover Sheet		
	a.	Model Name(s): Bosque Riparian Community Index Model for the Middle Rio Grande, Albuquerque, New Mexico
	b.	Functional Area: Ecosystem Restoration; Impact Assessment /Mitigation
	c.	Model Proponent: Albuquerque District
	d.	Model Developers ERDC-EL and Albuquerque District (with support from interagency and stakeholder participants)
1. Background		
	a.	Purpose of Model: The model was developed in an effort to quantify the value of diverse biological resources in this study area with the intent of capturing complex biotic patterns of the landscape. Refer to *Chapter 1*, "Purpose of the Models" for more detail.
	b.	Model Description and Depiction: The model was rendered in a HEP-compatible format. Model components were comprised of combinations of relevant parameters to characterize the hydrology, soils, biotic integrity, structure, spatial complexity, and disturbance regimes of the unique bosque riparian ecosystem occurring along the Middle Rio Grande Reach in central New Mexico. Model components (and their underlying variables) were normalized (scaled from 0.0 to 1.0) as required by traditional HEP procedures. Both flow charts ("ecosystem puzzles") and mathematical algorithms were used to depict the model herein. Refer to *Chapter 3* (*Model Flow Diagram*), *Chapter 4* (*Model Formulas*), and *Chapter 5* (*Model Concept* and *Steps 1-5)* for details relating to the individual model components and format.
	c.	Contribution to Planning Effort: The model helped to characterize the baseline conditions (in a quantitative manner) of the unique and significant ecological resources along the Middle Rio Grande Reach in central New Mexico. When applied within the HEP assessment paradigm, the study team will be able to evaluate and compare the benefits of proposed ecosystem restoration initiatives. Future

1 http://www.usace.army.mil/cw/cecw-cp/models/protocols_cert_7-02-07.pdf

		applications in the watershed could also use the model to evaluate and compare flood risk management measures and determine the ability of the proposed mitigation measures to offset these losses.
	d.	Description of Input Data: Both field and spatially-explicit (GIS) data are necessary to calculate the outputs. Refer to *Chapter 4* for a list of variables and appropriate sampling protocols and statistical data management activities.
	e.	Description of Output Data: Habitat Suitability Indices are output on a normalized scale of 0-1 in compliance with the traditional HEP paradigm. Within a standard HEP application, these indices can be multiplied by area to produce Habitat Units (HUs), and can be assessed over time under both With- and Without-project scenarios to generate Average Annual Habitat Units (AAHUs) (Refer to *Chapter 2 HEP Overview*).
	f.	Statement on the capabilities and limitations of the model: The model has been tested using reference data and conditions along the Middle Rio Grande Reach. It can be used to assess baseline conditions as well as assess both a No Action condition and proposed alternative designs in either an Impact/Mitigation study or within an Ecosystem Restoration context. The model should not be applied outside of the Rio Grande-Albuquerque watershed without review and recalibration.
	g.	Description of model development process including documentation on testing conducted (Alpha and Beta tests): A series of workshops were convened and experts contributed to the development of both the conceptual framework and the final index model presented here. The model was calibrated using reference data from across the model domain (Middle Rio Grande Reach – refer to Figure 9). Internal (ERDC-EL) peer review has commenced, and the authors are drafting several peer-reviewed journal articles for publication. Appendix G discusses the internal/external peer review process standard for ERDC-EL publications and model building efforts. *Chapter 3* discusses the model building process. *Chapter 4* discusses the model calibration process as well as the alpha/beta tests of the model to quantify baseline conditions for the study area.
2. Technical Quality		
	a.	Theory: In theory, the quantification of ecosystem function in these communities can be obtained by using indicators of ecosystem integrity and applying these in the well-documented, and accepted, HEP-based framework. The U.S. Fish and Wildlife Service (USFWS) published quantifiable procedures in 1980 to assess planning initiatives as they relate to change of fish and wildlife habitats (USFWS 1980a,1980b, and 1980c). These procedures, referred to collectively as Habitat Evaluation Procedures and known widely as HEP, use a habitat-based approach to assess ecosystems and provide a mechanism for quantifying changes in habitat quality and quantity over time under proposed alternative scenarios. Habitat Suitability Indices (HSIs) are simple mathematical algorithms that generate a unitless index derived as a function of one or more environmental variables that characterize or typify the site conditions (i.e., vegetative cover and composition, hydrologic regime, disturbance, etc.) and are deployed in the HEP framework to quantify the outcomes of restoration or impact scenarios. These tools have been applied many times over the course of the last 30 years (Williams 1988, VanHorne and Wiens 1991, Brooks 1997, Brown et al. 2000, Store and Jokimaki 2003, Shifley et al. 2006, Van der Lee et al. 2006). Virtually all attempts to use HSI models have been heavily criticized, and many criticisms are well deserved. In most instances, these criticisms have focused on the lack of: (a) identification of the appropriate context (spatial and temporal) for the model parameters, (b) a conceptual framework for what the model is indicating, (c) integration of science and values, and (d) validation of the models (Kapustka 2005, Barry et al. 2006, Hirzel et al. 2006, Inglis et al. 2006, Ray and Burgman 2006, Van

der Lee et al. 2006). A fundamental problem with these approaches continues to be the inability to link species presence or relative abundance with significant aspects of habitat quality (VanHorne and Wiens 1991) such as productivity.

Despite such criticisms, HSI models have played an important role in the characterization of ecosystem conditions nationwide. They represent a logical and relatively straightforward process for assessing change to fish and wildlife habitat (Williams 1988, VanHorne and Wiens 1991, Brooks 1997, Brown et al. 2000, Kapustka 2005). The controlled and economical means of accounting for habitat conditions makes HEP a decision-support process that is superior to techniques that rely heavily upon professional judgment and superficial surveys (Williams 1988, Kapustka 2005). They have proven to be invaluable tools in the development and evaluation of restoration alternatives (Williams 1988, Brown et al. 2000, Store and Kangas 2001, Kapustka 2003, Store and Jokimaki 2003, Gillenwater et al. 2006, Schluter et al. 2006, Shifley et al. 2006), managing refuges and nature preserves (Brown et al. 2000, Ortigosa et al. 2000, Store and Kangas 2001, Felix et al. 2004, Ray and Burgman 2006, Van der Lee et al. 2006) and others), and mitigating the effects of human activities on wildlife species (Burgman et al. 2001, NRC 2001, Van Lonkhuyzen et al. 2004). These modeling approaches emphasize usability. Efforts are made during model development to ensure that they are biologically valid and operationally robust. Most HSI models are constructed largely as working versions rather than as final, definitive models (VanHorne and Wiens 1991). Simplicity is implicitly valued over comprehensiveness, perhaps because the models need to be useful to field managers with little training or experience in this arena. The model structure is therefore simple, and the functions incorporated in the models are relatively easy to understand. The functions included in models are often based on published and unpublished information that indicates they are responsive to species density through direct or indirect effects on life requisites. The general approach of HSI modeling is valid, in that the suitability of habitat to a species is likely to exhibit strong thresholds below which the habitat is usually unsuitable and above which further changes in habitat features make little difference. And as such, most HSI models should be seen as quantitative expressions of the best understanding of the relations between easily measured environmental variables and habitat quality. Habitat suitability models, then, are a compromise between ecological realism and limited data and time (Vospernik et al. 2007).

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	b.	Description of system being represented by the model: The Middle Rio Grande bosque riparian ecosystem has been modeled here. *Chapter 3* offers community (ecosystem) characterization garnered from peer reviewed literature and gray literature generated by federal/local resource management agencies.
	c.	Analytical requirements and assumptions: Adequate sample sizes (30+ per variable) must be obtained to assure some level of precision (reduction of uncertainty). It is assumed that the user will adopt and follow the suggested sampling protocols detailed herein. Follow-on data management (calculation of means per variable) is straightforward and should not be difficult to emulate.
	d.	Conformance with Corps policies and procedures: As indicated in the PMIP, HEP is an accepted and approved approach to quantifying benefits/impacts for these types of studies (Refer to *Chapter 1, "Planning Model Certification"*). The protocol described herein was fully vetted through the ERDC review process, and participants in the workshops, as well as external reviewers, have been included in the process (Refer to *Chapter 2 – Model Review Process*). Outputs conform to Corps policies and procedures.
	e.	Identification of formulas used in the model and proof that the computations are appropriate and done correctly: Formulas can be found in *Chapter 3*. All spreadsheets used to organize data and the datafiles used to calculate outputs can be obtained from the District upon request (contact Ondrea Hummel – see Appendix D for contact information). ERDC-EL performed QA/QC on all spreadsheet and datafile operations and can describe these to the reviewers upon request.
3. System Quality		
	a.	Description and rationale for selection of supporting software tool/programming language and hardware platform: The **HEAT** software is a fully vetted software package currently undergoing model certification. The model described here is not software per se (Refer to *Chapter 1, "Planning Model Certification"*), and as such does not contain any programming. ArcMap, ArcToolbox, and Spatial Analyst are all commercially developed off-the-shelf software programs readily available to the user base.
	b.	Proof that the programming was done correctly: NA
	c.	Description of process used to test and validate model: Verification of the model can be found in *Chapter 4, "Model Verification"*.
	d.	Discussion of the ability to import data into other software analysis tools (interoperability issue): NA
4. Usability		
	a.	Availability of input data necessary to support the model: All data (presented in spreadsheet and database format) can be obtained from the District upon request (contact Ondrea Hummel – see Appendix D for contact information).
	b.	Formatting of output in an understandable manner: Outputs of the model are standard indices (HSI) - compatible with traditional HEP applications (scaled 0-1).
	c.	Usefulness of results to support project analysis: Model results have been successfully utilized in plan formulation and alternative comparison analyses for the Middle Rio Grande Bosque Ecosystem Restoration (MRGBER) Study.

	d.	Ability to export results into project management documentation: All outputs are MS Office-compatible and easily imported into MS Word and MS PowerPoint for documentation and distribution.
	e.	Training availability: **HEAT** software training was been provided to the Albuquerque District (and the MRGBER E-Team will receive a 5-day workshop in FY09) in 2006-2007. ERDC-EL also provides model building workshops at the local, regional, and national level through PROSPECT and/or on a reimbursable basis. The District was also required to perform 1/3 of all calculations and 1/3 of all spreadsheet management activities to assure successful technology transfer (“ownership”) of the model and the evaluations thereafter.
	f.	Users’ documentation availability and whether it is user friendly and complete: This document serves as the model “manual.” A draft manual for the **HEAT** software is currently undergoing certification (Burks-Copes et al., in preparation). And there are Ecological Service Manuals (ESMs) to support HEP applications (USFWS 1980a-c).
	g.	Technical support availability: ERDC-EL provides technical support on all products upon request and on a reimbursable basis.
	h.	Software/hardware platform availability to all or most users: The model was provided in both MS Word and MS Excel format and in **HEAT** datafiles to all study participants (including contractors and stakeholders). All data (presented in spreadsheet and database format) can be obtained from the District upon request (contact Ondrea Hummel – see Appendix D for contact information). The GIS data utilized herein is available upon request from the Albuquerque District.
	i.	Accessibility of the model: The model is accessible now, and will be posted on the System-wide Water Resources Program’s (SWWRP) Water Resources Depot website upon completion of ERDC-EL technical review (https://swwrp.usace.army.mil/DesktopDefault.aspx).
	j.	Transparency of model and how it allows for easy verification of calculations and outputs: The mathematical operations in the model have been clearly documented herein and can be easily transferred into any spreadsheet program for verification (a step ERDC-EL uses to QA/QC every model development activity). The outputs are scaled from 0-1 (1 = optimal functionality and 0 = not functioning). An interpretative table has been provided in *Chapter 4* to assist the user in conclusions.
	k.	Accessibility (where is model physically located?: Both the Albuquerque District and ERDC-EL will maintain separate and relatively permanent copies of all model information (NTE 7 years). The model will also be posted on the SWWRP website.

DEPARTMENT OF THE ARMY
MISSISSIPPI VALLEY DIVISION, CORPS OF ENGINEERS
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REPLY TO
ATTENTION OF:

CEMVD-RB-T 23 April 2009

MEMORANDUM FOR Commander, South Pacific Division
ATTN: (Paul Bowers, CESPD-PDC)

SUBJECT: Middle Rio Grande Bosque Feasibility, New Mexico General Investigation Detailed Feasibility Study, Ecosystem Restoration Planning Center of Expertise Endorsement of Review Plan

1. References:
   a. EC 1105-2-410, Review of Decision Documents, 22 August 2008.

2. The enclosed Review Plan (RP) complies with all applicable policy and provides an adequate peer review of the plan formulation, engineering, and environmental analyses, and other aspects of the plan development. The Ecosystem Restoration Planning Center of Expertise (ECO-PCX) has reviewed the RP and documentation of the review is attached.

3. The ECO-PCX concurs with the conclusion that Independent External Peer Review of this project is not necessary. Documentation and review of the Bosque Community Habitat Suitability Index Model is sufficient to demonstrate technical and system quality of the model for single-use on this project. Non-substantive changes to this RP do not require further approval.

3. The ECO-PCX recommends the RP for approval by the MSC Commander. Upon approval of the RP, please provide a copy of the approved RP, a copy of the MSC Commander approval memorandum, and the link to where the RP is posted on the District to Jodi Staebell and Valerie Ringold.

4. Thank you for the opportunity to assist in the preparation of the Review Plan. Please continue to coordinate the Agency Technical Review efforts outlined in the RP with the ECO-PCX.

Enclosure

Jodi K Staebell

Jodi Staebell
Operational Director,
National Ecosystem Planning
Center of Expertise

CF:
CEMVD-RB-T (D. Vigh, J. Staebell)
CEMVD-PD-N (Smith, Wilbanks)
CEPOA-EN-CW-PF (V. Ringold)
CESPD-PDC (P. Bowers, P. Devitt)
CESPD-PDS-P (F. Tabatai)
CESPA-PM-C (A. Austin-Johnson)
CESPA-PM-L (K. Schaeffer, M. Mann)

Appendix D: E-Team Participants

As described in the main report, a series of workshops were used to facilitate the development of the community-based index model compatible with the HEP application paradigm for the MRGBER feasibility study. Formal minutes were developed for each workshop and can be provided upon request from the Albuquerque District (contact Ondrea Hummel – refer to contact information below). Several federal, state, and local agencies, as well as local and regional experts from the stakeholder organizations, and private consultants, participated in the model workshops. A complete list of participants can be found in Table D1. It is important to note that attrition over the course of the study led to many changes in this original roster. The authors have attempted to include both the names of original participants as well as replacements and additions.

Table D1. Model development workshop(s) participants.

E-Team Members	Agency	Phone	Email Address
Abeyta, Cyndie	USFWS	(505) 761-4738	cyndie_abeyta@fws.gov
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Buntjer, Mike	USFWS	(505) 761-4733	Mike_Buntjer@fws.gov
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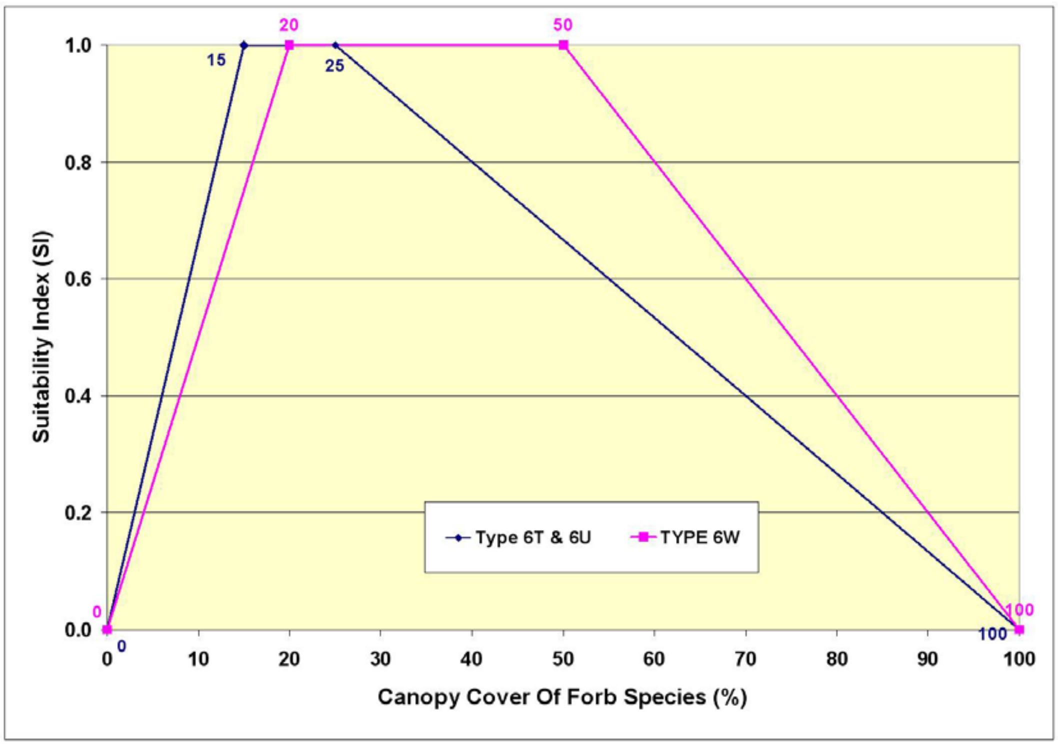
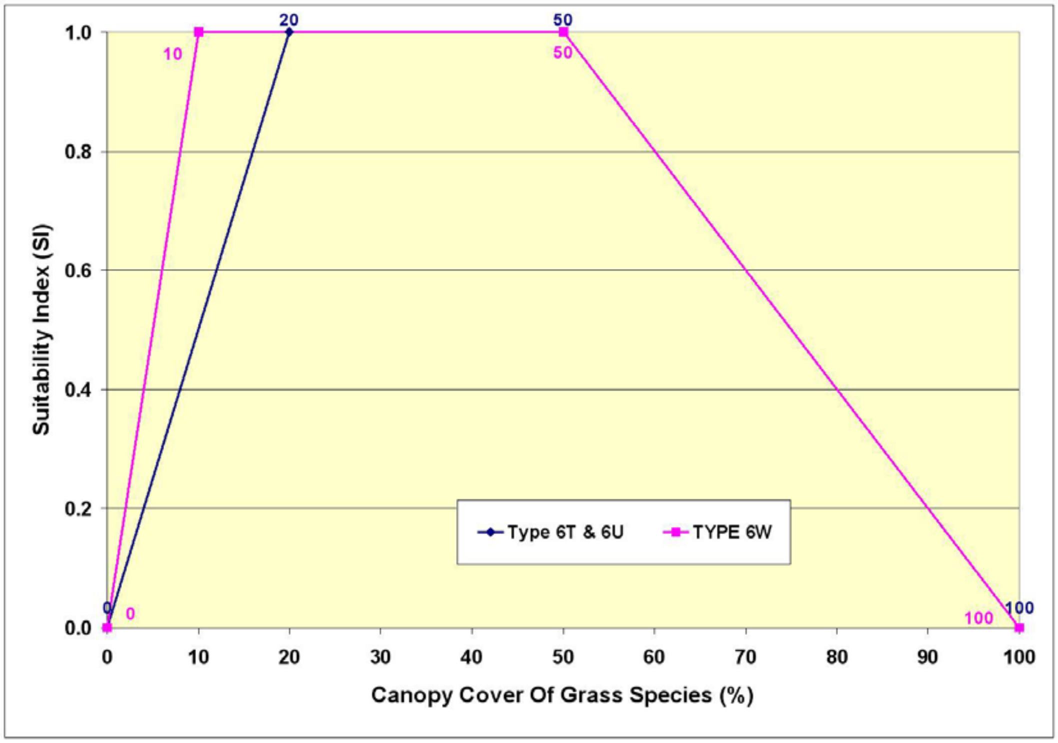
Appendix E: HSI Curves for the Bosque Riparian Model

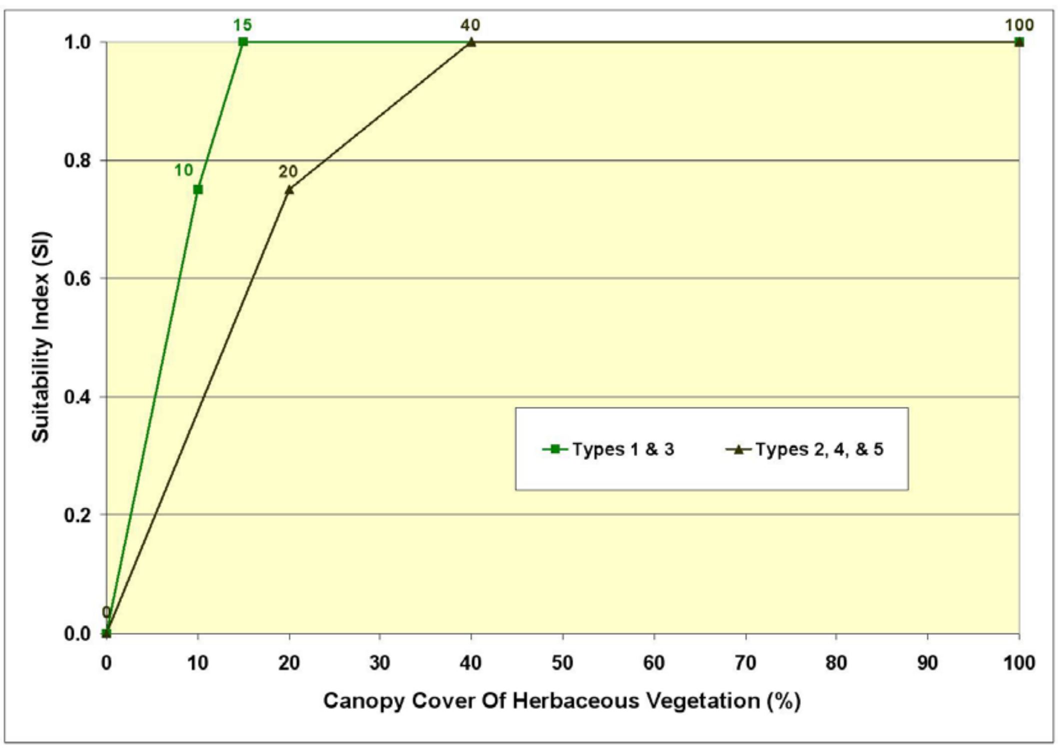
The following curves were developed by the E-Team to measure ecosystem function in the bosque communities found along the Middle Rio Grande Reach running through Albuquerque, New Mexico.[1]



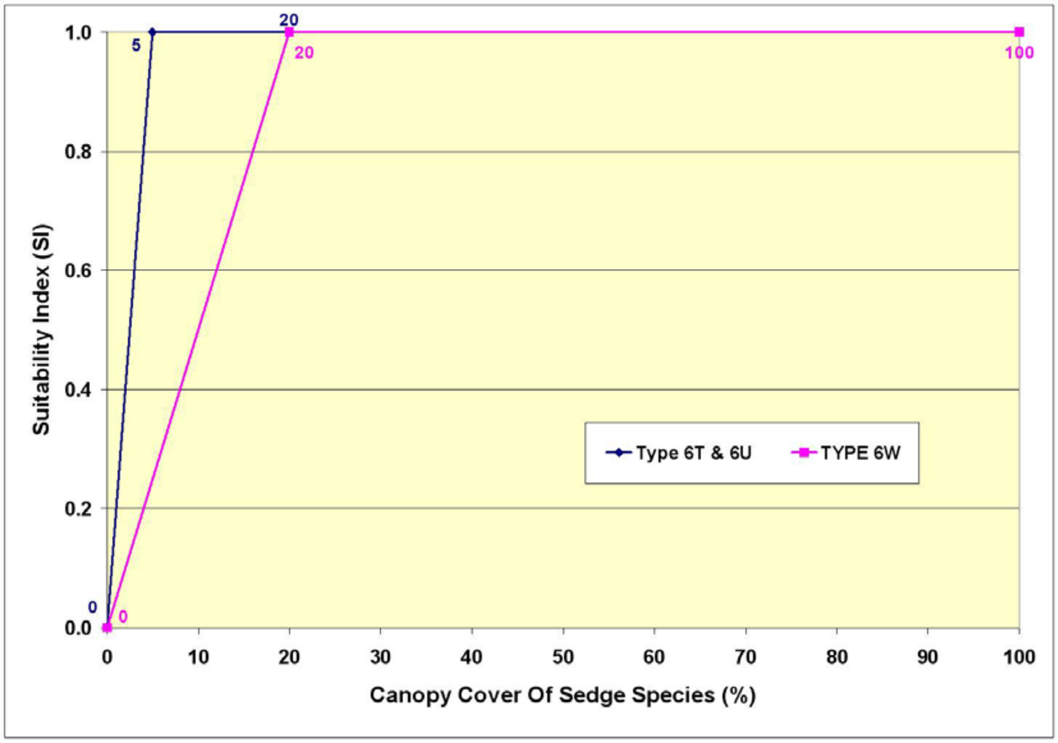
[1] Data are available upon request - contact the District POC (Ondrea Hummel, contact information can be found in *Appendix D*).



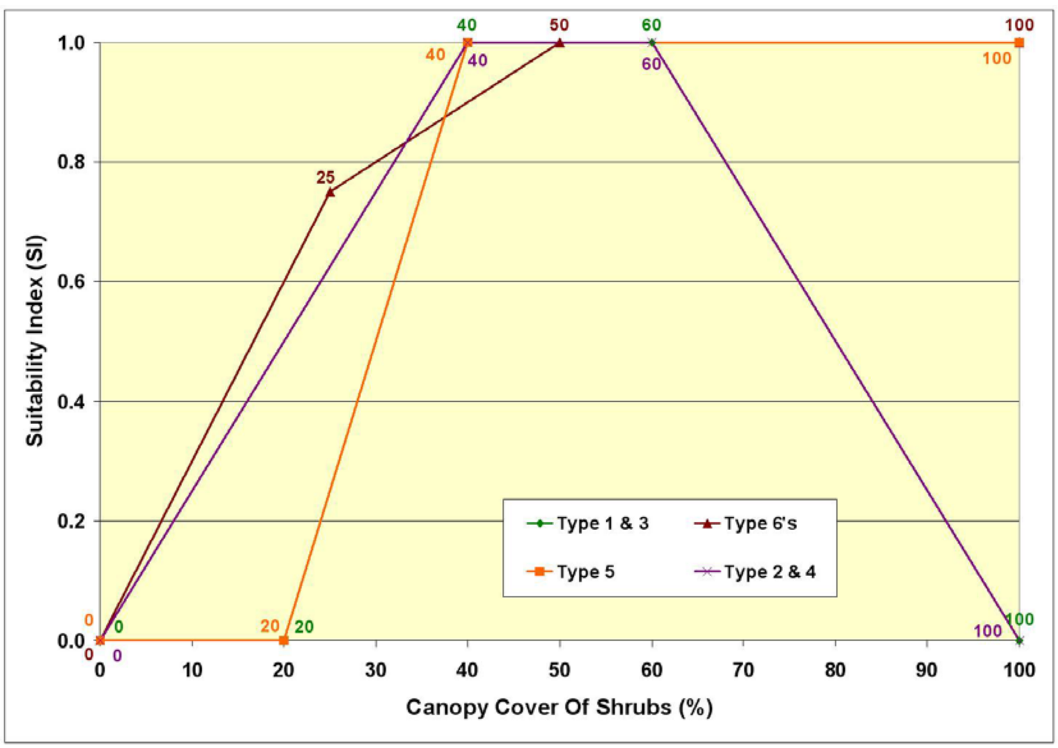
1.0
0.8
0.6
0.4
0.2
0.0
Suitability Index (SI)
0
10
20
30
40
50
60
70
80
90
100
Canopy Cover Of Grass Species (%)
Type 6T & 6U
TYPE 6W



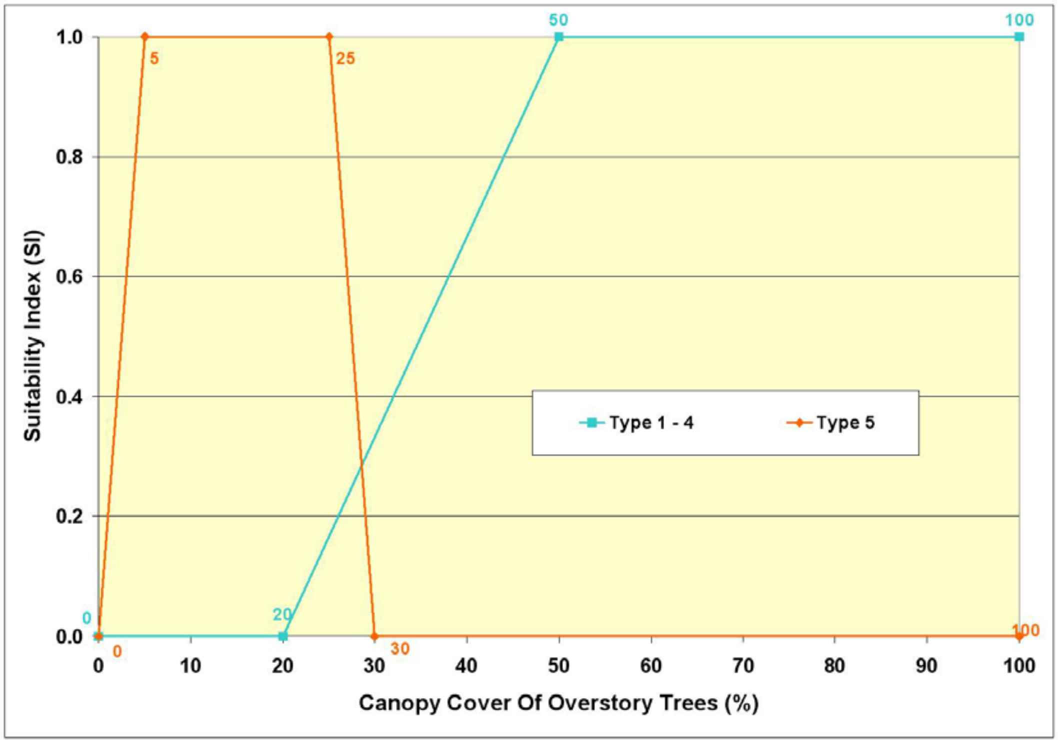
1.0
0.8
0.6
0.4
0.2
0.0
Suitability Index (SI)
0
10
20
30
40
50
60
70
80
90
100
Canopy Cover Of Herbaceous Vegetation (%)
Types 1 & 3
Types 2, 4, & 5

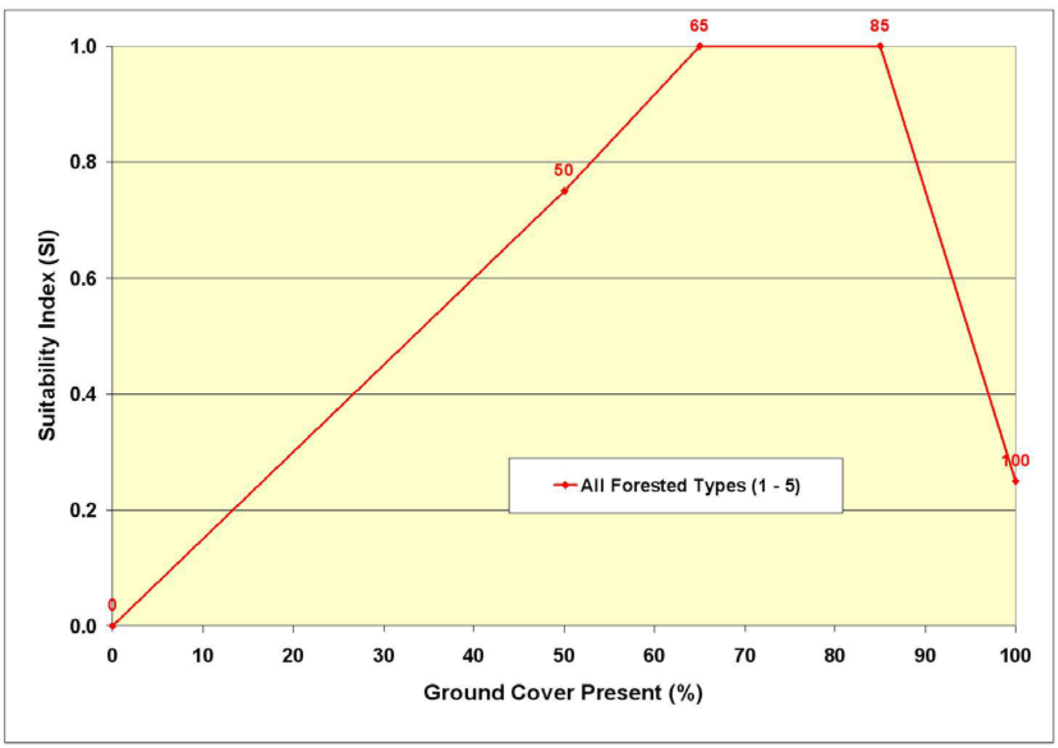


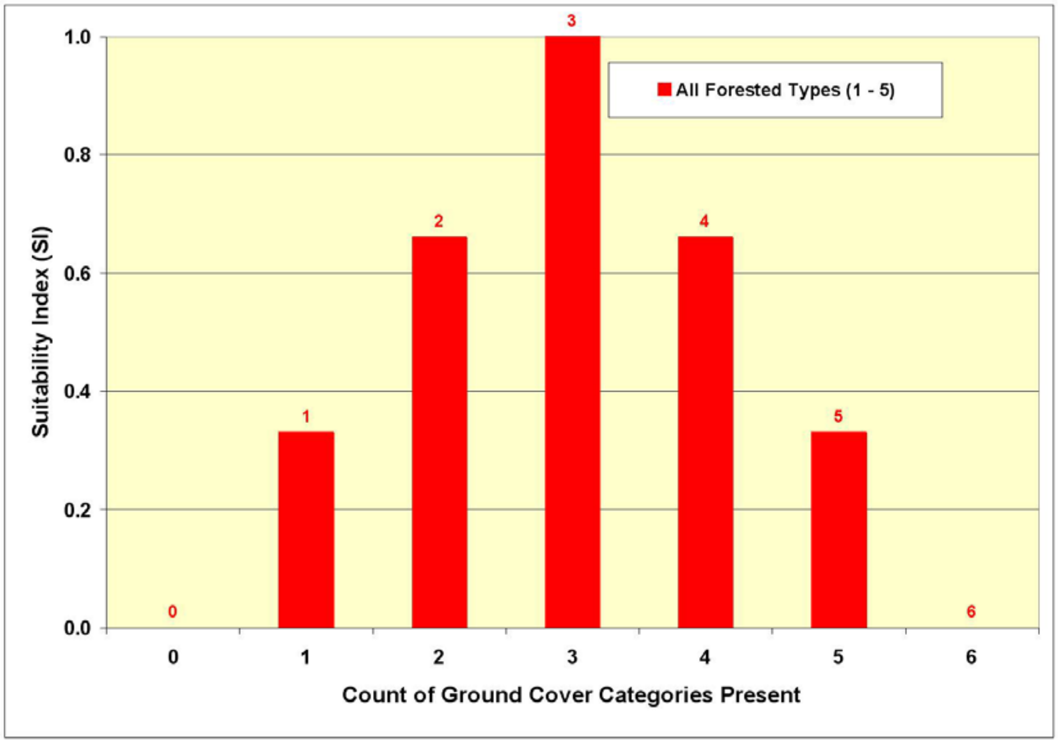
Suitability Index (SI)
1.0
0.8
0.6
0.4
0.2
0.0
0
10
20
30
40
50
60
70
80
90
100
Canopy Cover Of Sedge Species (%)
Type 6T & 6U
TYPE 6W
5
20
100
0

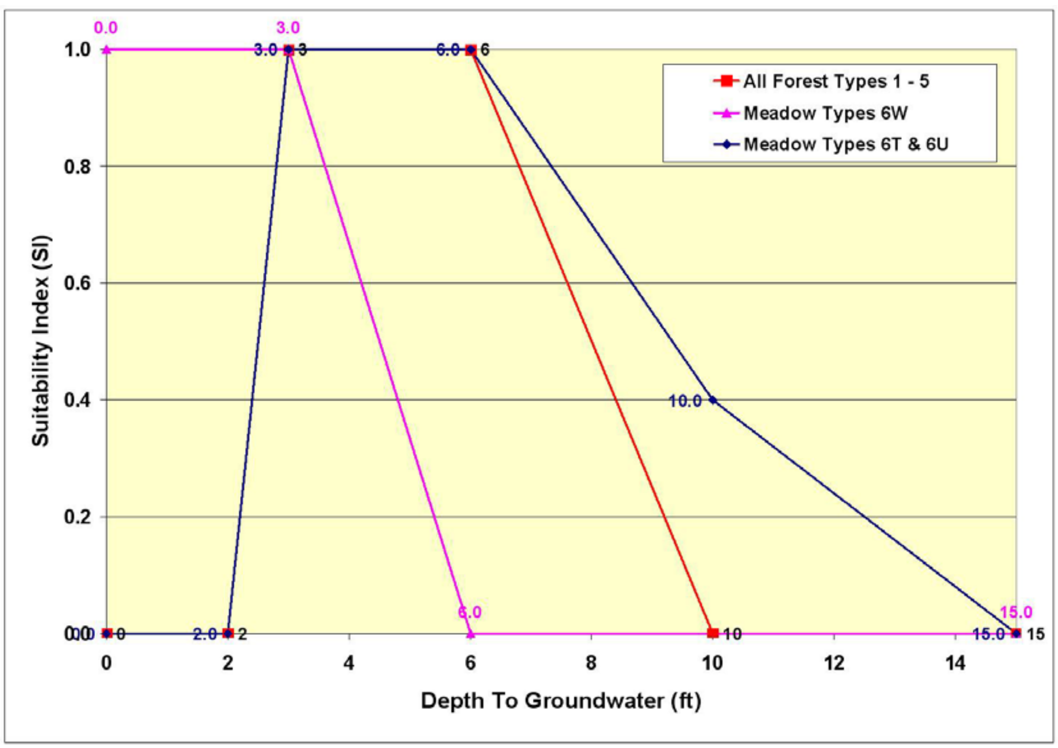


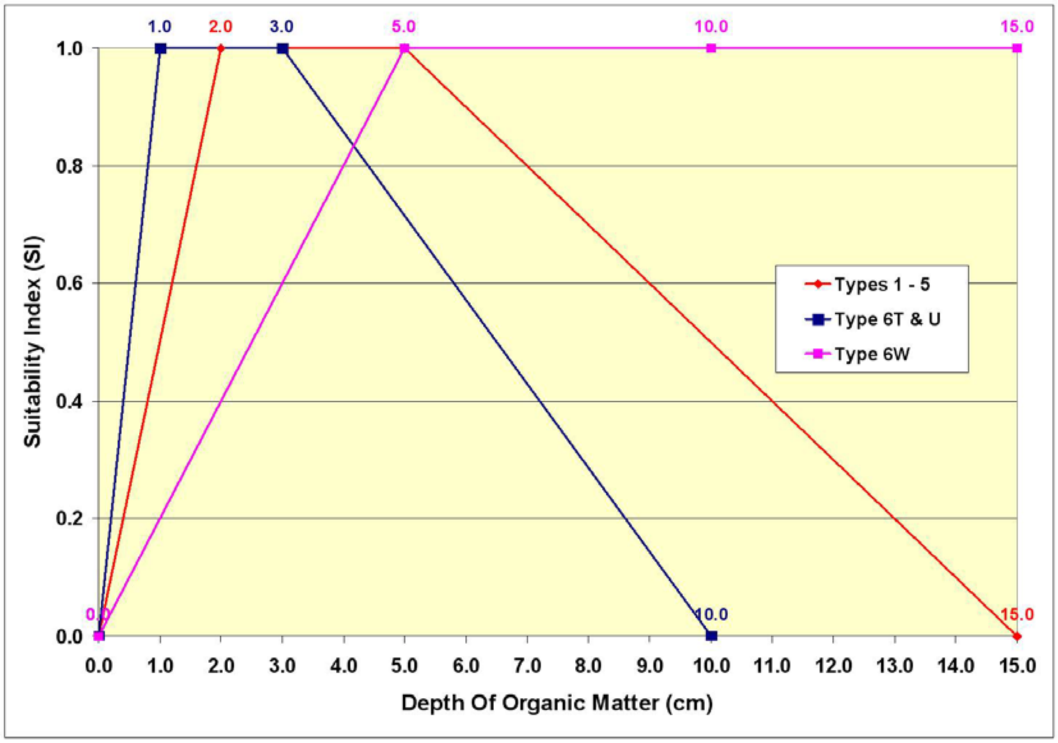
Suitability Index (SI)
1.0
0.8
0.6
0.4
0.2
0.0
0
10
20
30
40
50
60
70
80
90
100
Canopy Cover Of Shrubs (%)
Type 1 & 3
Type 6's
Type 5
Type 2 & 4
25
40
50
60
100


1.0
0.8
0.6
0.4
0.2
0.0
Suitability Index (SI)
0
10
20
30
40
50
60
70
80
90
100
Canopy Cover Of Overstory Trees (%)
Type 1 - 4
Type 5
0
0
5
25
20
30
50
100
100

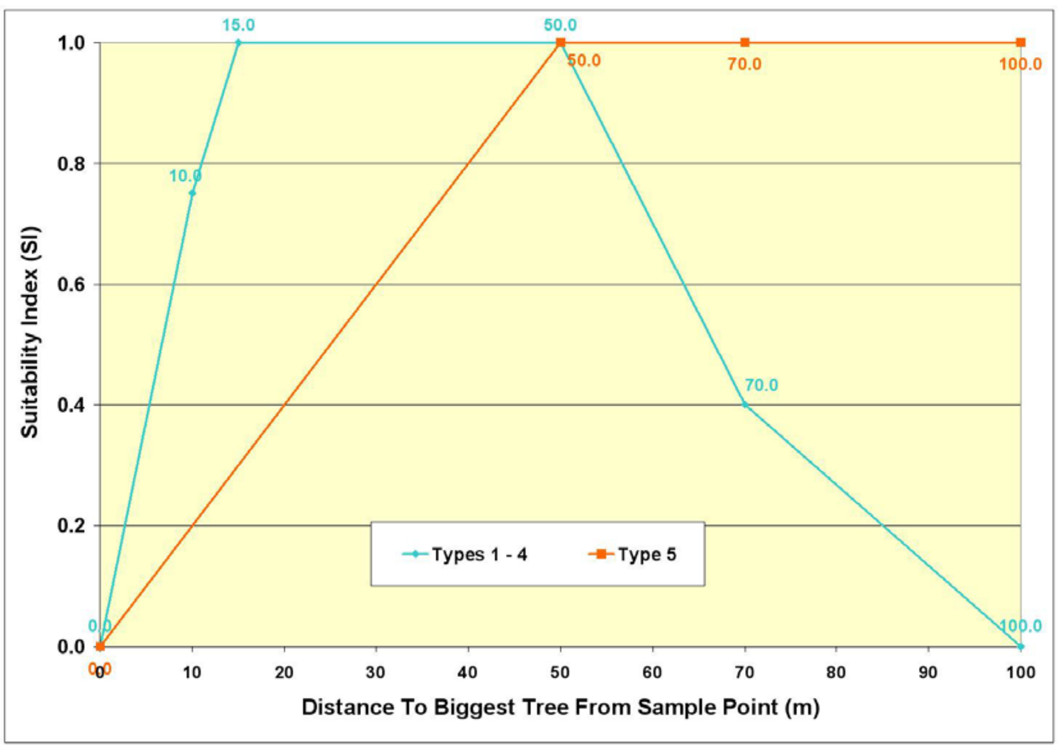

1.0
0.8
0.6
0.4
0.2
0.0
Suitability Index (SI)
0
10
20
30
40
50
60
70
80
90
100
Ground Cover Present (%)
All Forested Types (1 - 5)
0
50
65
85
100


All Forested Types (1 - 5)
Suitability Index (SI)
1.0
0.8
0.6
0.4
0.2
0.0
0
1
2
3
4
5
6
Count of Ground Cover Categories Present

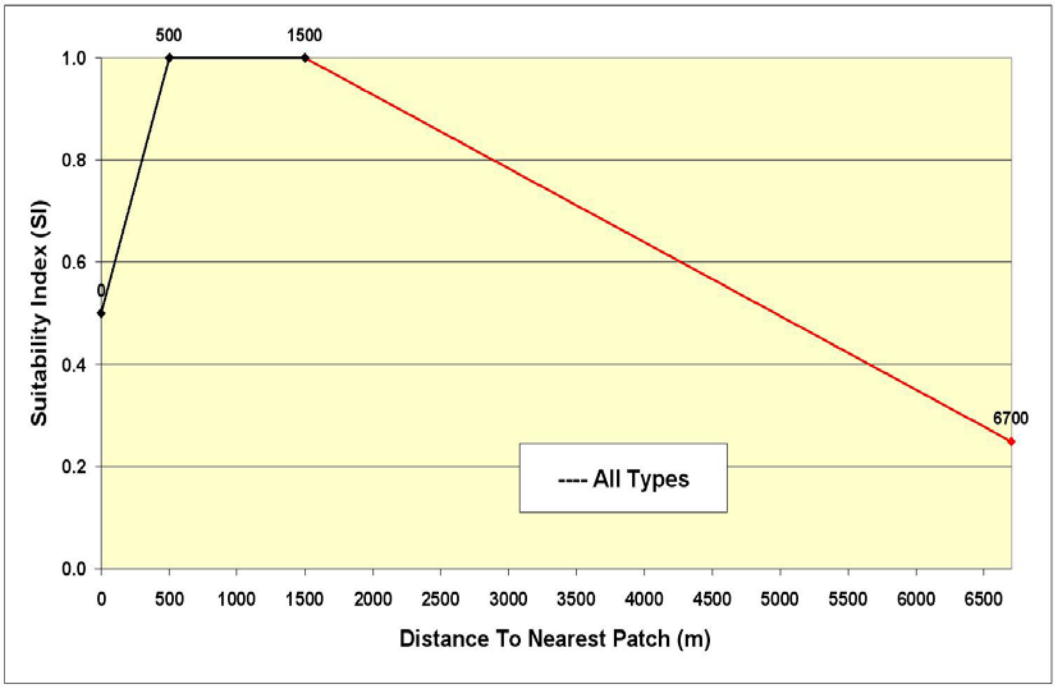

All Forest Types 1 - 5
Meadow Types 6W
Meadow Types 6T & 6U
Suitability Index (SI)
1.0
0.8
0.6
0.4
0.2
0.0
0
2
4
6
8
10
12
14
Depth To Groundwater (ft)
0.0
3.0
6.0
10.0
15.0

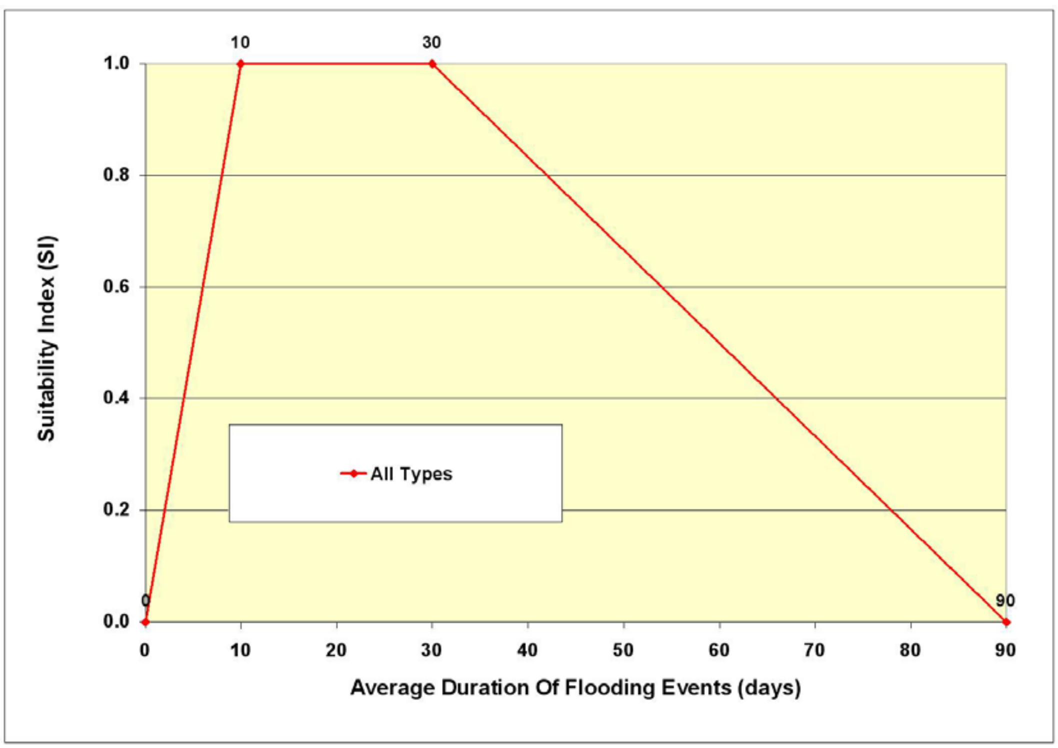


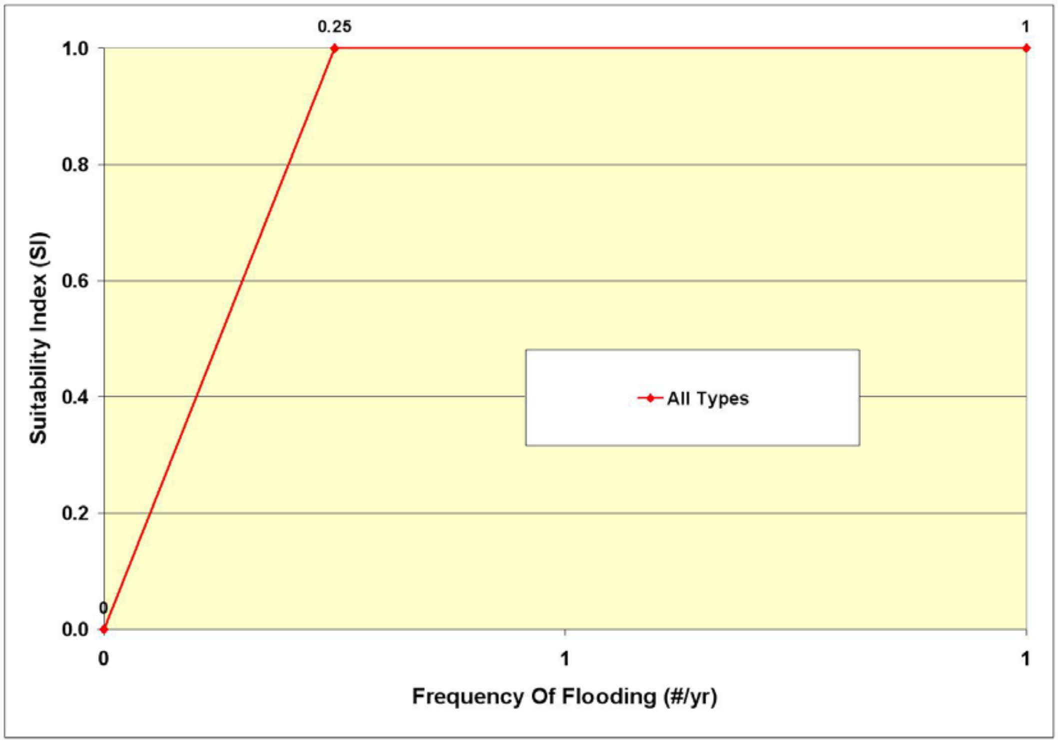
Suitability Index (SI)
Depth Of Organic Matter (cm)
Types 1 - 5
Type 6T & U
Type 6W

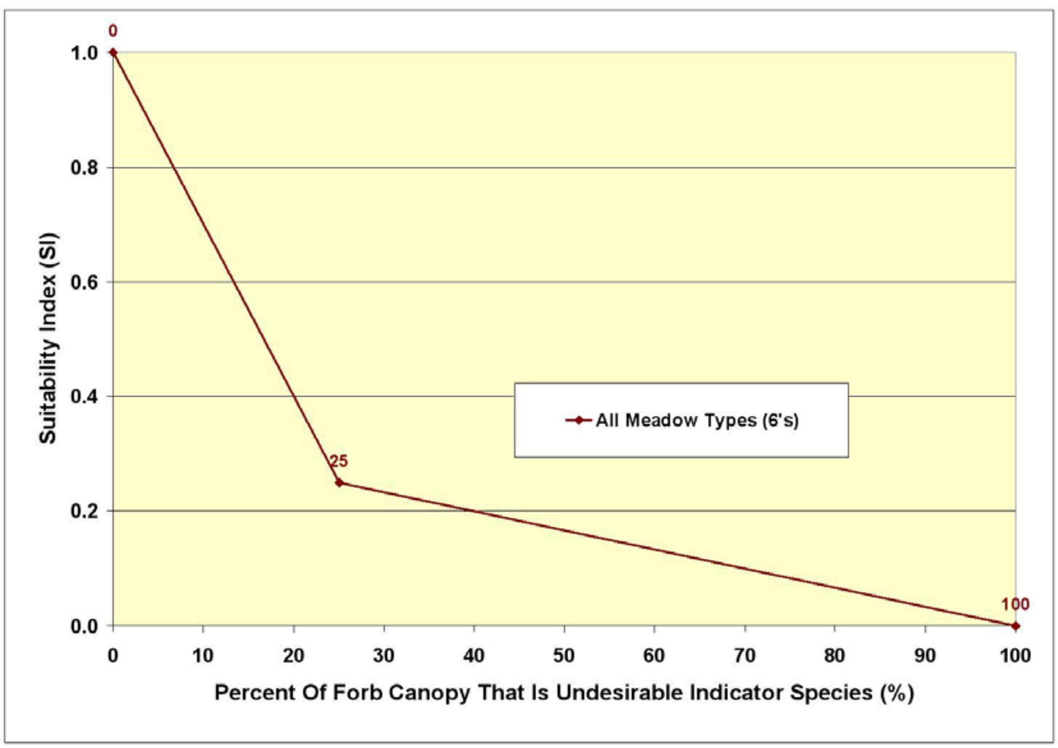


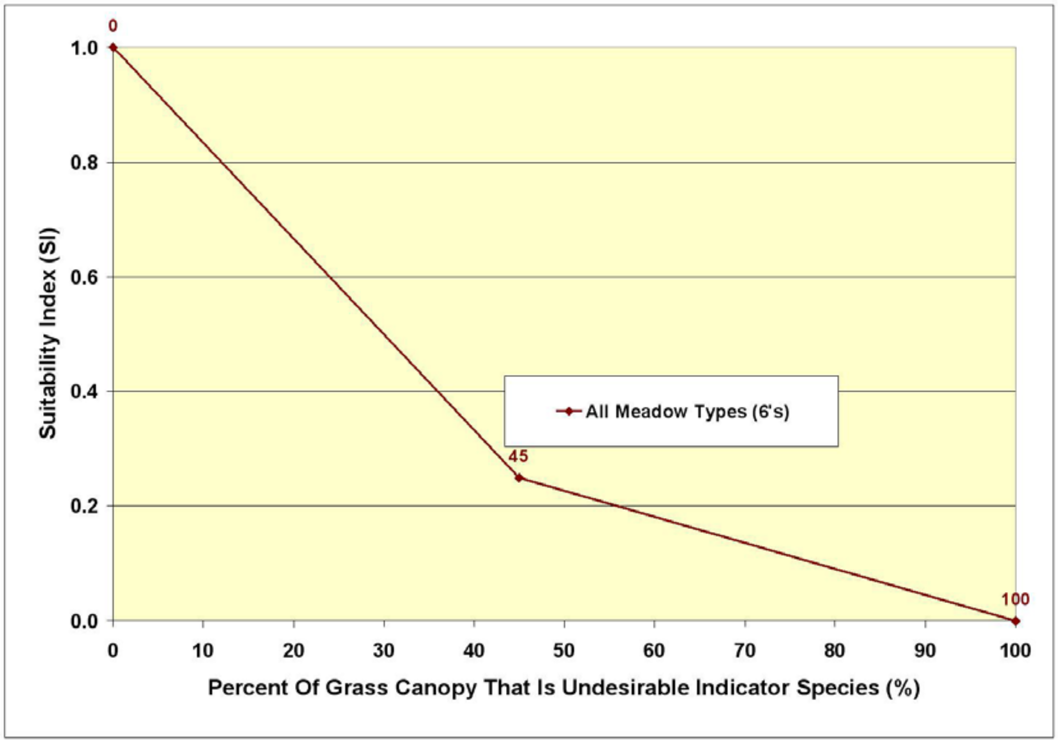
Suitability Index (SI)
Distance To Biggest Tree From Sample Point (m)
Types 1 - 4
Type 5


500
1500
1.0
0.8
0.6
0.4
0.2
0.0
0
6700
Suitability Index (SI)
---- All Types
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
Distance To Nearest Patch (m)

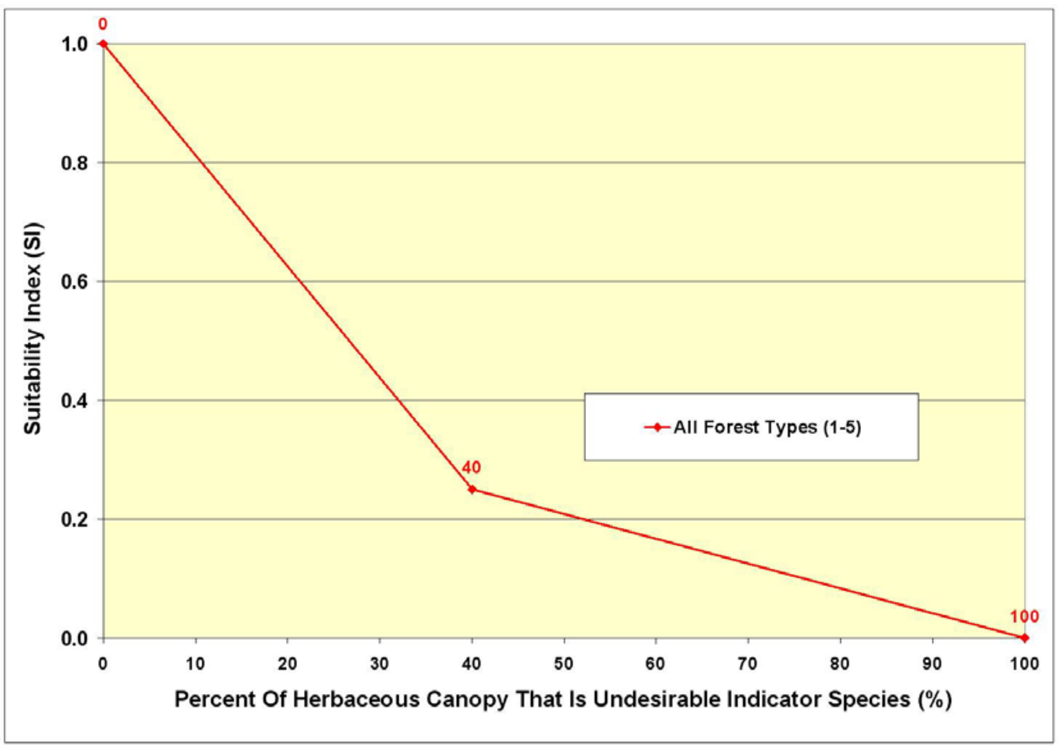

10
30
1.0
0.8
0.6
0.4
0.2
0.0
0
90
Suitability Index (SI)
All Types
0
10
20
30
40
50
60
70
80
90
Average Duration Of Flooding Events (days)


0.25
1
1.0
0.8
0.6
0.4
0.2
0.0
0
Suitability Index (SI)
All Types
0
1
1
Frequency Of Flooding (#/yr)

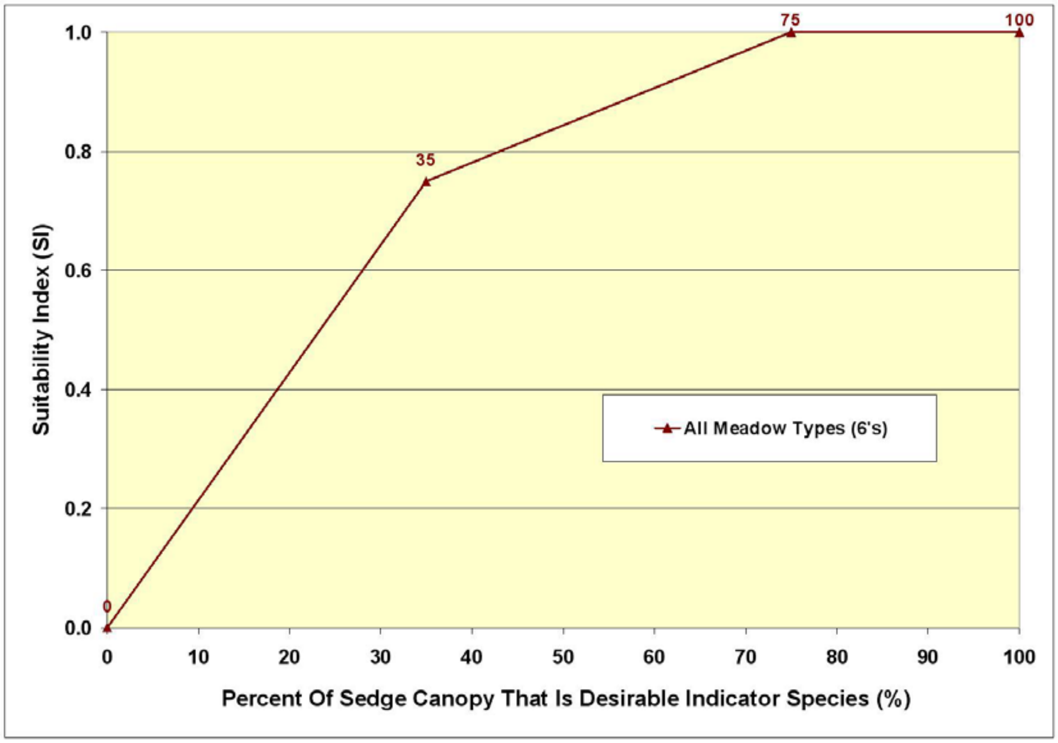

0
1.0
0.8
0.6
0.4
0.2
0.0
Suitability Index (SI)
All Meadow Types (6's)
25
100
0
10
20
30
40
50
60
70
80
90
100
Percent Of Forb Canopy That Is Undesirable Indicator Species (%)

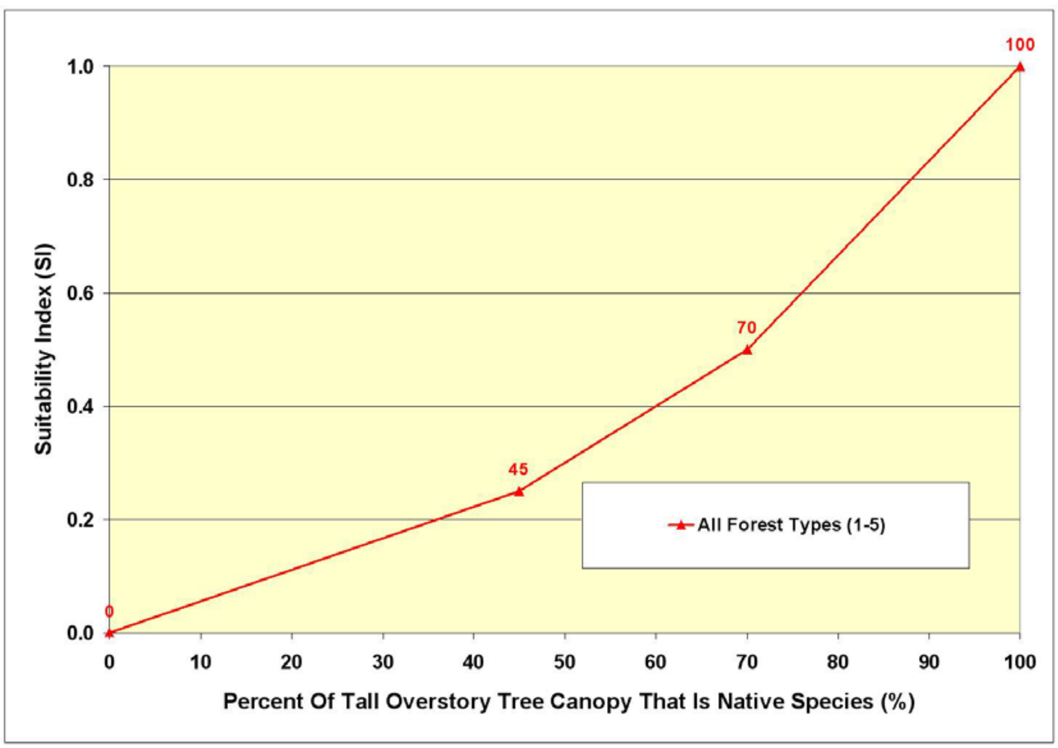


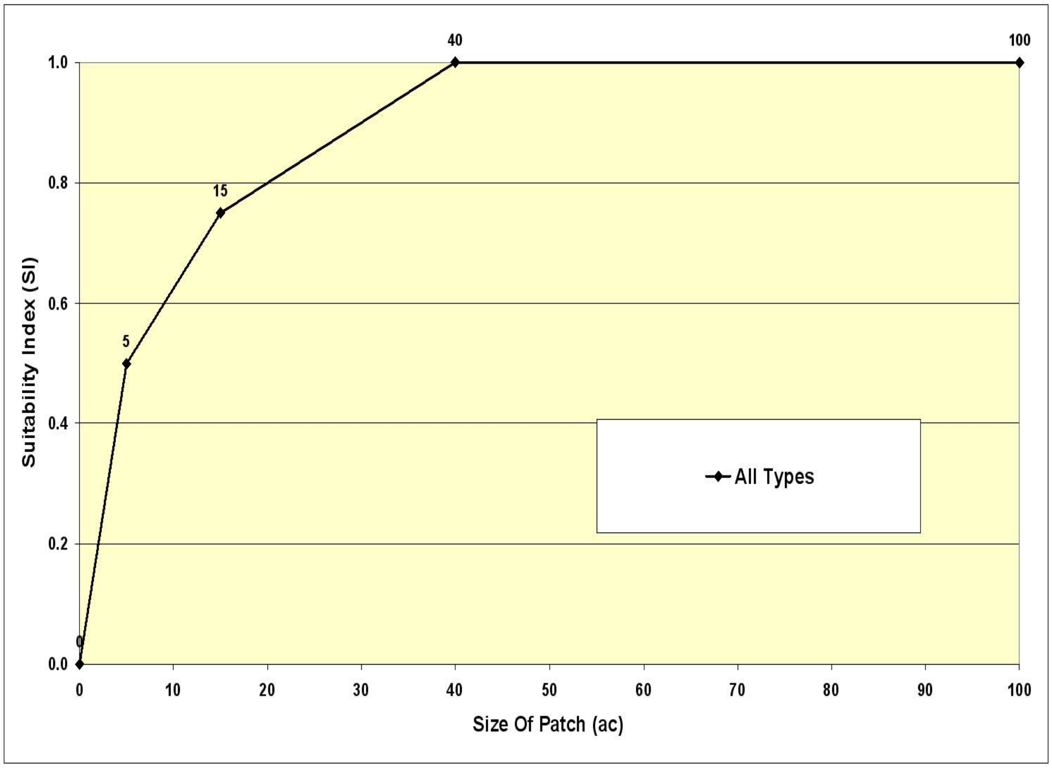
0
1.0
0.8
0.6
0.4
0.2
0.0
Suitability Index (SI)
All Meadow Types (6's)
45
100
0
10
20
30
40
50
60
70
80
90
100
Percent Of Grass Canopy That Is Undesirable Indicator Species (%)



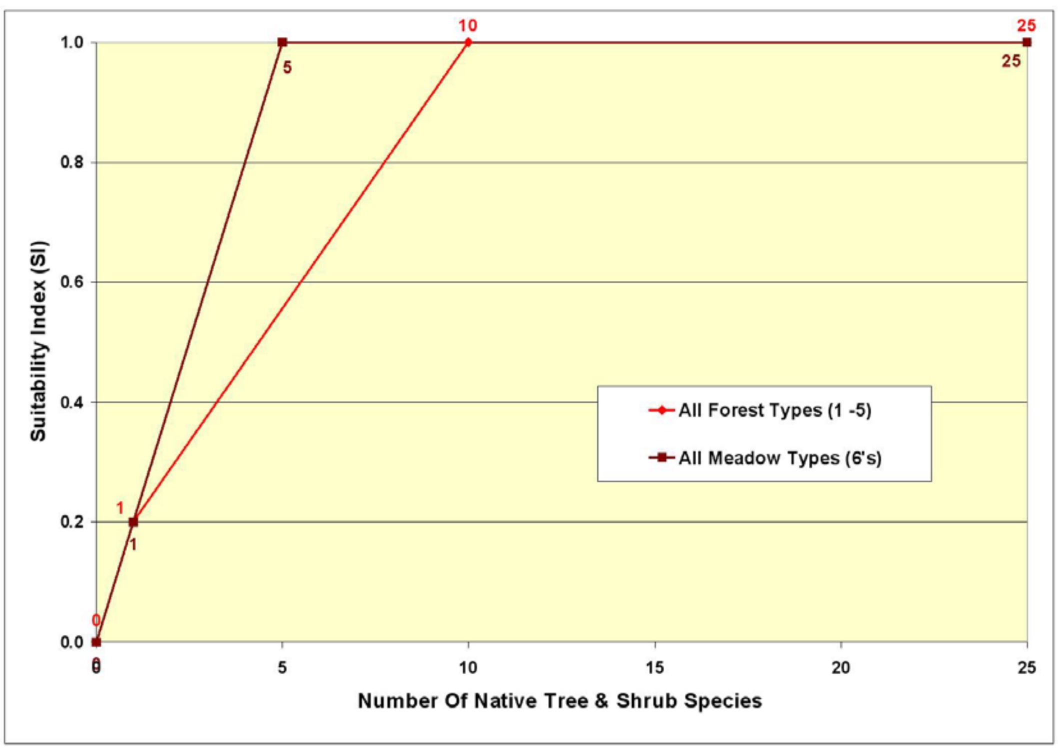
0
1.0
0.8
0.6
0.4
0.2
0.0
Suitability Index (SI)
All Forest Types (1-5)
40
100
0
10
20
30
40
50
60
70
80
90
100
Percent Of Herbaceous Canopy That Is Undesirable Indicator Species (%)


1.0
0.8
0.6
0.4
0.2
0.0
Suitability Index (SI)
0
35
75
100
All Meadow Types (6's)
0 10 20 30 40 50 60 70 80 90 100
Percent Of Sedge Canopy That Is Desirable Indicator Species (%)

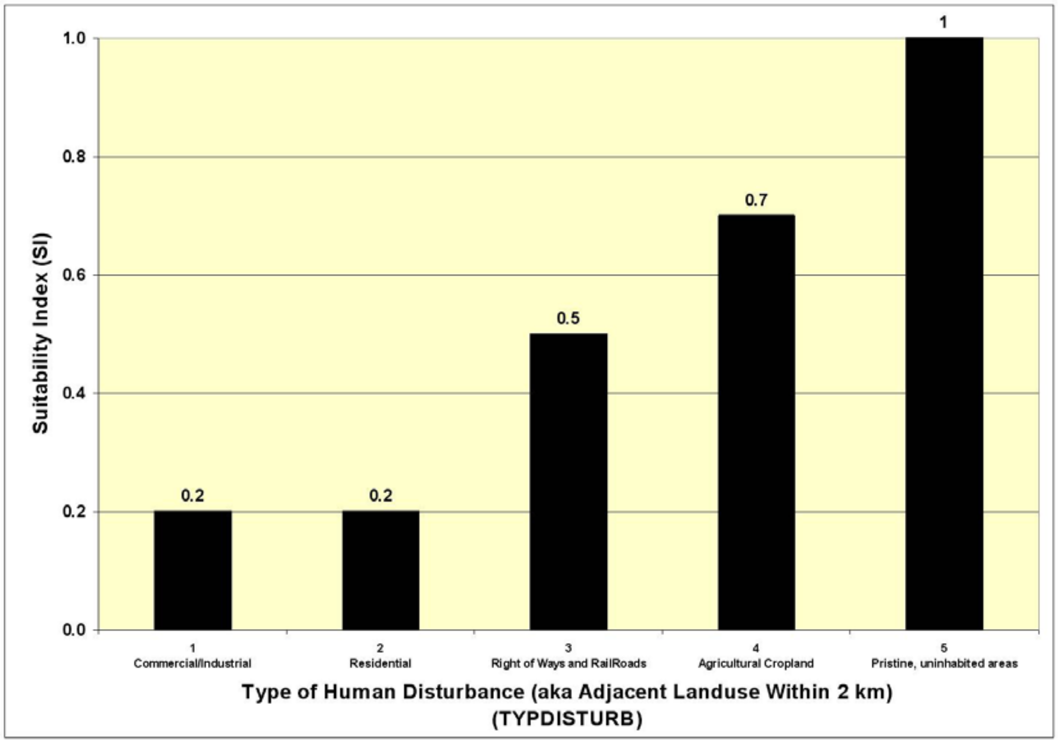

1.0
0.8
0.6
0.4
0.2
0.0
Suitability Index (SI)
0
45
70
100
All Forest Types (1-5)
0 10 20 30 40 50 60 70 80 90 100
Percent Of Tall Overstory Tree Canopy That Is Native Species (%)

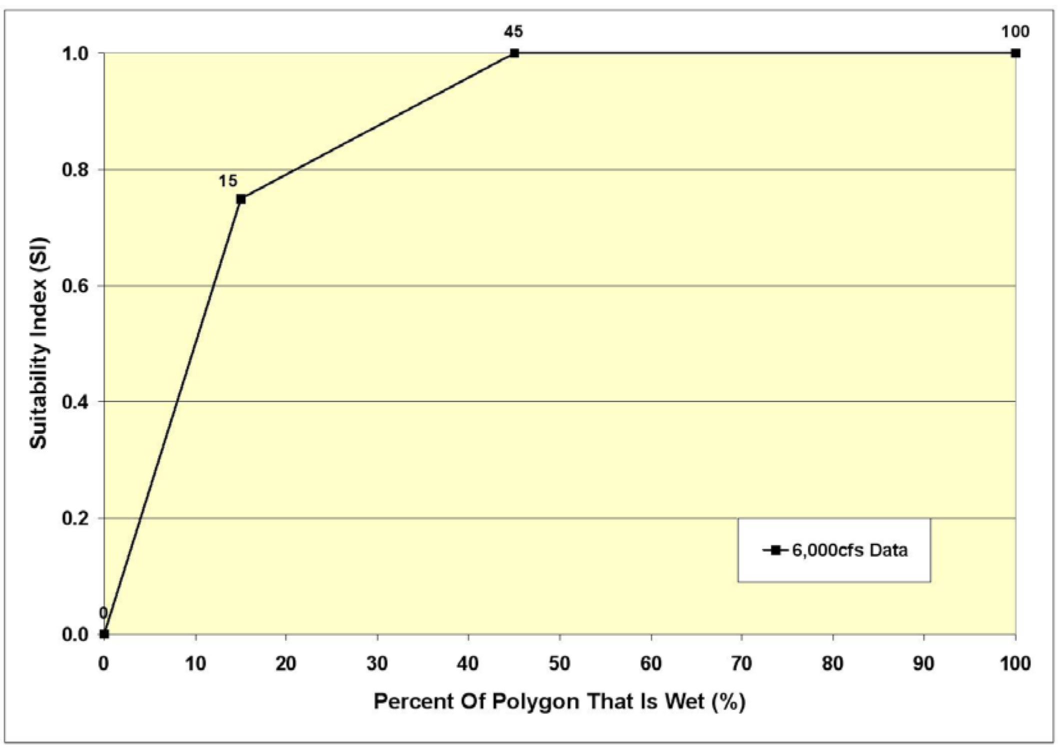


Suitability Index (SI)
1.0
0.8
0.6
0.4
0.2
0.0
0
5
15
40
100
All Types
0 10 20 30 40 50 60 70 80 90 100
Size Of Patch (ac)



Suitability Index (SI)
1.0
0.8
0.6
0.4
0.2
0.0
0
1
5
10
25
All Forest Types (1 -5)
All Meadow Types (6's)
0 5 10 15 20 25
Number Of Native Tree & Shrub Species


1.0
0.8
0.6
0.4
0.2
0.0
Suitability Index (SI)
0.2
0.2
0.5
0.7
1
1
Commercial/Industrial
2
Residential
3
Right of Ways and RailRoads
4
Agricultural Cropland
5
Pristine, uninhabited areas
Type of Human Disturbance (aka Adjacent Landuse Within 2 km)
(TYPDISTURB)


1.0
0.8
0.6
0.4
0.2
0.0
Suitability Index (SI)
0
15
45
100
6,000cfs Data
0
10
20
30
40
50
60
70
80
90
100
Percent Of Polygon That Is Wet (%)

Appendix F: Useful Field Protocols and Checklists for the Bosque Riparian Model

Several checklists or crosswalks have been included in this appendix to assist the field in the application of the HSI model.

- For those readers accustomed to the Hink and Ohmart (1984) vegetative classification system (H&O system), this appendix provides a crosswalk between it and the cover typing classification system used in the HSI model (Table F2).
- A list of “desirable” and “undesirable” species is also provided that will be needed to record both the indicator and native variables (Tables F3 and F4).
- Finally, direction and diagrams are provided to assist in the measurement of the various vegetative variables for the HSI model (i.e., point-intercept, line-intercept, point-centered quarter).

H&O Classification System

The “Middle Rio Grande Biological Survey” completed by Hink and Ohmart in 1984 described the plant communities within the study area’s riparian zone and provided detailed information on species composition and the structure of cover types (Table F1).

Table F1. Vegetation structure categories using modified Hink & Ohmart classification.

Structure Type	Dominant Overstory Height (ft)	Overstory Cover (%)	Understory Cover (%)	General Description
1s	>40	>25	25-50	Tall trees with well developed understory
1f	>40	>25	>50	Tall trees with very dense understory
2	>40	>25	<25	Tall trees with little of not understory
3s	20-40	>25	25-50	Intermediate-sized trees with medium understory density
3f	20-40	>25	>50	Intermediate-sized trees with dense understory
4	20-40	>25	<25	Scattered woodlands of intermediate-sized trees
5s	<20	>25	25-50	Shrubs with medium density
5f	<20	>25	>50	Dense shrubby growth
6	<20	<25	<25	Sparse and/or very young shrubs

Table F2. Crosswalk between the commonly used Hink and Omart vegetative classification system and the Bosque Riparian HSI Model's cover type classification naming conventions

H&O Code	Hink & Omart Description	Scientific Name (*Genus species*)	HSI Cover Type
ATX-SS5	Four-wing salt bush-Sand sage, Type 5	*Atriplex canescens-Oligosporus filifolius*	TYPE 5
ATX-SS6	Four-wing salt bush-Sand sage, Type 6	*Atriplex canescens-Oligosporus filifolius*	TYPE 6U
B-CW5	Bulrush-Coyoto Willow, Type 5	*Scirpus spp.-Salix exigua*	TYPE 5
BD6	Broom dalea, Type 6	*Dalea scoparia*	TYPE 6U
C/A2t	Cottonwood overstory/Atriplex understory, Type 2, treated	*Populus fremontii var. wislizenii/Atriplex canescens*	TYPE 2T
C/B-A3	Cottonwood/Bulrush-Atriplex, Type 3	*Populus fremontii var. wislizenii/Scirpus-Atriplex canescens*	TYPE 3
C/C5pt	Cottonwood/Cottonwood, planted and treated	*Populus fremontii var. wislizenii*	TYPE 5
C/C6bpt	Cottonwood/Cottonwood, burned, planted and treated	*Populus fremontii var. wislizenii*	TYPE 6T
C/CW1	Cottonwood/Coyote Willow, Type 1	*Populus fremontii var. wislizenii/Salix exigua*	TYPE 1
C/CW1t	Cottonwood/Coyote Willow, Type 1, treated	*Populus fremontii var. wislizenii/Salix exigua*	TYPE 2T
C/CW3	Cottonwood/Coyote Willow, Type 3	*Populus fremontii var. wislizenii/Salix exigua*	TYPE 3
C/CW3S	Cottonwood/Coyote Willow, Type 3, sparse	*Populus fremontii var. wislizenii/Salix exigua*	TYPE 3
C/CW3t	Cottonwood/Coyote Willow, Type 3, treated	*Populus fremontii var. wislizenii/Salix exigua*	TYPE 3
C/CW4	Cottonwood/Coyote Willow, Type 4	*Populus fremontii var. wislizenii/Salix exigua*	TYPE 4U
C/CW-RO1	Cottonwood/Coyote Willow-Russian olive, Type 1	*Populus fremontii var. wislizenii/Salix exigua-Elaeagnus angustifolia*	TYPE 1
C/LC3bpt	Cottonwood overstory/(wolfberry) understory, Type 3	*Populus fremontii var. wislizenii/Lycium*	TYPE 3
C/MB2t	Cottonwood/Mulberry, Type 2, treated	*Populus fremontii var. wislizenii/Morus*	TYPE 2T
C/MB2t	Cottonwood/Mulberry, Type 2, treated	*Populus fremontii var. wislizenii/Morus*	TYPE 2T
C/MB-TW1t	Cottonwood/Mulberry-Tree Willow (Peach-leaf willow or Goodding willow), Type 1, treated	*Populus fremontii var. wislizenii/Morus/Salix*	TYPE 1
C/NMO1	Cottonwood/New Mexico olive, Type 1	*Populus fremontii var. wislizenii/Forestiera neomexicana*	TYPE 1
C/NMO1S	Cottonwood/New Mexico olive, Type 1, sparse	*Populus fremontii var. wislizenii/Forestiera neomexicana*	TYPE 1
C/NMO2t	Cottonwood/New Mexico olive, Type 2, treated	*Populus fremontii var. wislizenii/Forestiera neomexicana*	TYPE 2T
C/NMO3	Cottonwood/New Mexico olive, Type 3,	*Populus fremontii var. wislizenii/Forestiera neomexicana*	TYPE 3
C/NMO3t	Cottonwood/New Mexico olive, Type 3, treated	*Populus fremontii var. wislizenii/Forestiera neomexicana*	TYPE 3
C/NMO-RO1	Cottonwood/New Mexico olive-Russian olive, Type 1	*Populus fremontii var. wislizenii/Forestiera neomexicana-Elaeagnus angustifolia*	TYPE 1
C/NMO-SC-RO1	Cottonwood/New Mexico olive-Salt cedar-Russian olive, Type 1	*Populus fremontii var. wislizenii/Forestiera neomexicana-Tamarix chinensis-Elaeagnus angustifolia*	TYPE 1
C/RO1	Cottonwood/Russian olive, Type 1	*Populus fremontii var. wislizenii/Elaeagnus angustifolia*	TYPE 1

H&O Code	Hink & Omart Description	Scientific Name (*Genus species*)	HSI Cover Type
C/RO15	Cottonwood/Russian olive, Type 15	*Populus fremontii var. wislizenii/Elaeagnus angustifolia*	TYPE 5
C/RO1F	Cottonwood/Russian olive, Type 1, Flycatcher	*Populus fremontii var. wislizenii/Elaeagnus angustifolia*	TYPE 1
C/RO1S	Cottonwood/Russian olive, Type 1, sparse	*Populus fremontii var. wislizenii/Elaeagnus angustifolia*	TYPE 1
C/RO2	Cottonwood/Russian olive, Type 2	*Populus fremontii var. wislizenii/Elaeagnus angustifolia*	TYPE 2U
C/RO2t	Cottonwood/Russian olive, Type 2, treated	*Populus fremontii var. wislizenii/Elaeagnus angustifolia*	TYPE 2T
C/RO3	Cottonwood/Russian olive, Type 3	*Populus fremontii var. wislizenii/Elaeagnus angustifolia*	TYPE 3
C/RO-CW1	Cottonwood/Russian olive-Coyote Willow, Type 1	*Populus fremontii var. wislizenii/Elaeagnus angustifolia-Salix exigua*	TYPE 1
C/RO-CW3	Cottonwood/Russian olive-Coyote Willow, Type 3	*Populus fremontii var. wislizenii/Elaeagnus angustifolia-Salix exigua*	TYPE 3
C/RO-NMO-SC1	Cottonwood/Russian olive-New Mexico olive-Salt cedar, Type 1	*Populus fremontii var. wislizenii/Elaeagnus angustifolia-Forestiera neomexicana-Tamarix chinensis*	TYPE 1
C/RO-SC1	Cottonwood/Russian olive-Salt cedar, Type 1	*Populus fremontii var. wislizenii/Elaeagnus angustifolia-Tamarix chinensis*	TYPE 1
C/RO-SC3	Cottonwood/Russian olive-Salt cedar, Type 3	*Populus fremontii var. wislizenii/Elaeagnus angustifolia-Tamarix chinensis*	TYPE 3
C/SC1	Cottonwood/Salt cedar, Type 1	*Populus fremontii var. wislizenii/Tamerix chinensis*	TYPE 1
C/SC2pt	Cottonwood/Salt cedar, Type 2, planted, treated	*Populus fremontii var. wislizenii/Tamerix chinensis*	TYPE 2T
C/SC3S	Cottonwood/Salt cedar, Type 3, sparse	*Populus fremontii var. wislizenii/Tamerix chinensis*	TYPE 3
C/SC4	Cottonwood/Salt cedar, Type 4	*Populus fremontii var. wislizenii/Tamerix chinensis*	TYPE 4U
C/SC-CW5	Cottonwood/Salt cedar-Coyote Willow, Type 5	*Populus fremontii var. wislizenii/Tamerix chinensis-Salix exigua*	TYPE 5
C/SC-RO1	Cottonwood/Salt cedar-Russian olive, Type 1	*Populus fremontii var. wislizenii/Tamerix chinensis-Elaeagnus angustifolia*	TYPE 1
C/SE1	Cottonwood/Siberian elm, Type 1	*Populus fremontii var. wislizenii/Ulmus pumila*	TYPE 1
C/SE2t	Cottonwood/Siberian elm, Type2, treated	*Populus fremontii var. wislizenii/Ulmus pumila*	TYPE 2T
C/TH1	Cottonwood/Tree of Heaven, Type 1	*Populus fremontii var. wislizenii/Ailanthus altissima*	TYPE 1
C/TH-SE2t	Cottonwood/Tree of Heaven-Siberian elm, Type 2, treated	*Populus fremontii var. wislizenil/Ailanthus altissima-Ulmus pumila*	TYPE 2T
C/TH-SE4t	Cottonwood/Tree of Heaven-Siberian elm, Type 4, treated	*Populus fremontii var. wislizenii/Ailanthus altissima-Ulmus pumila*	TYPE 4T
C/TW1t	Cottonwood/Peach-leaf willow or Goodding willow, Type 1, treated	*Populus fremontii var. wislizenii/Salix gooddingii*	TYPE 1
C/TW2t	Cottonwood/Peach-leaf willow or Goodding willow, Type 2, treated	*Populus fremontii var. wislizenii/Salix gooddingii*	TYPE 2T
C2	Cottonwood, Type 2	*Populus fremontii var. wislizenii*	TYPE 2U
C2bpt	Cottonwood, Type 2, burned, planted and treated	*Populus fremontii var. wislizenii*	TYPE 2T
C2p	Cottonwood, Type 2, planted	*Populus fremontii var. wislizenii*	TYPE 2U
C2pt	Cottonwood, Type 2, planted, treated	*Populus fremontii var. wislizenii*	TYPE 2T
C2t	Cottonwood, Type 2, treated	*Populus fremontii var. wislizenii*	TYPE 2T

H&O Code	Hink & Omart Description	Scientific Name (*Genus species*)	HSI Cover Type
C4	Cottonwood, Type 4	*Populus fremontii var. wislizenii*	TYPE 4U
C4bpt	Cottonwood, Type 4, burned, planted and treated	*Populus fremontii var. wislizenii*	TYPE 4T
C4pt	Cottonwood, Type 4, planted and treated	*Populus fremontii var. wislizenii*	TYPE 4T
C4t	Cottonwood, Type 4, treated	*Populus fremontii var. wislizenii*	TYPE 4T
C5Sbpt	Cottonwood, Type 5, sparse, burned, planted and treated	*Populus fremontii var. wislizenii*	TYPE 5
C5Spt	Cottonwood, Type 5, sparse, planted and treated	*Populus fremontii var. wislizenii*	TYPE 5
C5St	Cottonwood, Type 5, sparse, treated	*Populus fremontii var. wislizenii*	TYPE 5
C5t	Cottonwood, Type 5, treated	*Populus fremontii var. wislizenii*	TYPE 5
C6bpt	Cottonwood, Type 6, burned, planted and treated	*Populus fremontii var. wislizenii*	TYPE 6T
C-CW5p	Cottonwood-Coyote Willow, Type 5, planted	*Populus fremontii var. wislizenii-Salix exigua*	TYPE 5
C-MB/MB1t	Cottonwood-Mulberry/Mulberry, type 1, treated	*Populus fremontii var. wislizenii-Morus/Morus*	TYPE 1
C-RO4	Cottonwood-Russian olive, Type 4	*Populus fremontii var. wislizenii-Elaeagnus angustifolia*	TYPE 4U
C-RO	Cottonwood-Russian olive	*Populus fremontii var. wislizenii-Elaeagnus angustifolia*	TYPE 5
C-RO/RO3	Cottonwood-Russian olive/Russian olive, Type 3	*Populus fremontii var. wislizenii-Elaeagnus angustifolia/Elaeagnus angustifolia*	TYPE 3
C-RO4pt	Cottonwood-Russian olive, Type 4, planted, treated	*Populus fremontii var. wislizenii-Elaeagnus angustifolia*	TYPE 4T
C-RO-TW5	Cottonwood-Russian olive-Tree Willow (Peach-leaf willow or Goodding willow), Type 5	*Populus fremontii var. wislizenii-Elaeagnus angustifolia/Salix gooddingii*	TYPE 5
C-SC/SC1	Cottonwood-Salt cedar/Salt cedar, Type 1	*Populus fremontii var. wislizenii-Tamarix L/Tamerix chinensis*	TYPE 1
C-SC2	Cottonwood-Salt cedar, Type 2	*Populus fremontii var. wislizenii-Tamerix chinensis*	TYPE 2U
C-SE/CW3	Cottonwood-Siberian elm/Coyote Willow, Type 3	*Populus fremontii var. wislizenii-Ulmus pumila L./Salix exigua*	TYPE 3
C-SE/RO1	Cottonwood-Siberian elm/Russian olive, Type 1	*Populus fremontii var. wislizenii-Ulmus pumila L./Elaeagnus angustifolia*	TYPE 1
C-SE/SC1	Cottonwood-Siberian elm/Salt cedar, Type 1	*Populus fremontii var. wislizenii-Ulmus pumila L./Tamerix chinensis*	TYPE 1
C-SE/SC2	Cottonwood-Siberian elm/Salt cedar, Type 2	*Populus fremontii var. wislizenii-Ulmus pumila L./Tamerix chinensis*	TYPE 2U
C-SE/SE2t	Cottonwood-Siberian elm/Siberian elm, Type 2, treated	*Populus fremontii var. wislizenii-Ulmus pumila L./Ulmus pumila L.*	TYPE 2T
C-SE-TW/SC1	Cottonwood-Siberian elm/Tree Willow (Peach-leaf willow or Goodding willow)/Salt cedar, Type 1	*Populus fremontii var. wislizenii-Ulmus pumila L./Salix gooddingii/Tamerix chinensis*	TYPE 1
C-TH3	Cottonwood-Tree of Heaven, Type 3	*Populus fremontii var. wislizenii-Ailanthus altissima*	TYPE 3
C-TW/CW3	Cottonwood-Tree Willow (Peach-leaf willow or Goodding willow)/Coyote Willow, Type 3	*Populus fremontii var. wislizenii-Salix gooddingii/Salix exigua*	TYPE 3

H&O Code	Hink & Omart Description	Scientific Name (*Genus species*)	HSI Cover Type
C-TW/TH2pt	Cottonwood-Tree Willow (Peach-leaf willow or Goodding willow)/Tree of Heaven, Type 2, planted and treated	*Populus fremontii var. wislizenii-Salix gooddingii/Ailanthus altissima*	TYPE 2T
C-TW4t	Cottonwood-Tree Willow (Peach-leaf willow or Goodding willow), Type 4, treated	*Populus fremontii var. wislizenii-Salix gooddingii*	TYPE 4T
C-TW5pt	Cottonwood-Tree Willow (Peach-leaf willow or Goodding willow), Type 5, planted and treated	*Populus fremontii var. wislizenii-Salix gooddingii*	TYPE 5
C-TW6bpt	Cottonwood-Tree Willow (Peach-leaf willow or Goodding willow), Type 6, burned, planted and treated	*Populus fremontii var. wislizenii-Salix gooddingii*	TYPE 6T
C-TW-SC5bpt	Cottonwood-Tree Willow (Peach-leaf willow or Goodding willow)-Salt cedar, Type 5, burned, planted and treated	*Populus fremontii var. wislizenii-Salix gooddingii-Tamerix chinensis*	TYPE 5
C-TW-SE2t	Cottonwood-Tree Willow (Peach-leaf willow or Goodding willow)-Siberian elm, Type 2, treated	*Populus fremontii var. wislizenii-Salix gooddingii-Populus fremontii var. wislizenii*	TYPE 2T
CW5	Coyote Willow, Type 5	*Salix exigua*	TYPE 5
CW5	Coyote Willow, Type 5	*Salix exigua*	TYPE 5
CW5bt	Coyote Willow, Type 5, burned, treated	*Salix exigua*	TYPE 5
CW5F	Coyote Willow, Type 5, Flycatcher	*Salix exigua*	TYPE 5
CW5t	Coyote Willow, Type 5, treated	*Salix exigua*	TYPE 5
CW6	Coyote Willow, Type 6	*Salix exigua*	TYPE 6U
CW6C-RO/CW6	Coyote Willow, Type 6, Cottonwood-Russian olive/Coyote Willow, Type 6	*Salix exigua, Populus fremontii var. wislizenii-Elaeagnus angustifolia/Salix exigua*	TYPE 6U
CW6pt	Coyote Willow, Type 6, planted, treated	*Salix exigua*	TYPE 6T
CW6S	Coyote Willow, Type 6, sparse	*Salix exigua*	TYPE 6U
CW6t	Coyote Willow, Type 6, treated	*Salix exigua*	TYPE 6T
CW-B-CAT6	Coyote Willow-Bulrush-Cattail, Type 6	*Salix exigua-Scirpus-Typha*	TYPE 6U
CW-C5	Coyote Willow-Cottonwood, Type 5	*Salix exigua-Elaeagnus angustifolia*	TYPE 5
CW-C6	Coyote Willow-Cottonwood, Type 6	*Salix exigua-Elaeagnus angustifolia*	TYPE 6U
CW-CAT6	Coyote Willow-Cattail, Type 6	*Salix exigua-Typha*	TYPE 6U
CW-RO5	Coyote Willow-Russian olive, Type 5	*Salix exigua-Elaeagnus angustifolia*	TYPE 5
CW-RO5F	Coyote Willow-Russian olive, Type 5, Flycatcher	*Salix exigua-Elaeagnus angustifolia*	TYPE 5
CW-RO6	Coyote Willow-Russian olive, Type 6	*Salix exigua-Elaeagnus angustifolia*	TYPE 6U
CW-RO-SC5	Coyote Willow-Russian olive-Salt cedar, Type 5	*Salix exigua-Elaeagnus angustifolia-Tamerix chinensis*	TYPE 5
CW-SC6	Coyote Willow-Salt cedar, Type 6	*Salix exigua-Tamerix chinensis*	TYPE 6U
CW-TW5	Coyote Willow-Tree Willow (Peach-leaf willow or Goodding willow), Type 5	*Salix exigua-Salix gooddingii*	TYPE 5
MB6t	Mulberry, Type 6, treated	*Morus*	TYPE 6T

H&O Code	Hink & Omart Description	Scientific Name (*Genus species*)	HSI Cover Type
MB-SE6t	Mulberry-Siberian elm, Type 6, treated	*Morus-Ulmus pumila L*	TYPE 6T
MH5	Marsh, Type 5	*Morass*	TYPE 5
MH5-OW	Marsh, Type 5-Open Water	*Morass*	TYPE 5
MH6	Marsh, Type 6	*Morass*	TYPE 6W
NMO-CW5	New Mexico olive-Coyote Willow, Type 5	*Forestiera neomexicana-Salix exigua*	TYPE 5
NMO-SB5	New Mexico olive-Sandbar, Type 5	*Forestiera neomexicana-Salix interior*	TYPE 5
OP	Open land		OPENLAND
OPbpt	Open land, burned, planted and treated		OPENLAND
OPpt	Open land, planted and treated		OPENLAND
OPt	Open land, treated		OPENLAND
OW	Open water		OPENWATER
OWb	Open water, burned		OPENWATER
OW-MH5	Open water-Marsh, Type 5		TYPE 5
RO/CW3	Russian olive/Coyote Willow, Type 3	*Elaeagnus angustifolia/Salix exigua*	TYPE 3
RO3	Russian olive, Type 3	*Elaeagnus angustifolia*	TYPE 3
RO5	Russian olive, Type 5	*Elaeagnus angustifolia*	TYPE 5
RO5b	Russian olive, Type 5, burned	*Elaeagnus angustifolia*	TYPE 5
RO6	Russian olive, Type 6	*Elaeagnus angustifolia*	TYPE 6U
RO-C4	Russian olive-Cottonwood, Type 4	*Elaeagnus angustifolia-Populus fremontii var. wislizenii*	TYPE 4U
RO-C6	Russian olive-Cottonwood, Type 6	*Elaeagnus angustifolia-Populus fremontii var. wislizenii*	TYPE 6U
RO-CW5	Russian olive-Coyote Willow, Type 5	*Elaeagnus angustifolia-Salix exigua*	TYPE 5
RO-CW5F	Russian olive-Coyote Willow, Type 5, Flycatcher	*Elaeagnus angustifolia-Salix exigua*	TYPE 5
RO-CW6	Russian olive-Coyote Willow, Type 6	*Elaeagnus angustifolia-Salix exigua*	TYPE 6U
RO-SC3	Russian olive-Salt cedar, Type 3	*Elaeagnus angustifolia-Tamerix chinensis*	TYPE 3
RO-SC5	Russian olive-Salt cedar, Type 5	*Elaeagnus angustifolia-Tamerix chinensis*	TYPE 5
RO-SE-SC5S	Russian olive-Siberian elm, Salt cedar, Type 5, sparse	*Elaeagnus angustifolia-Ulmus pumila-Tamerix chinensis*	TYPE 5
SC3	Salt cedar, Type 3	*Tamerix chinensis*	TYPE 3
SC5	Salt cedar, Type 5	*Tamerix chinensis*	TYPE 5
SC5F	Salt cedar, Type 5. Flycatcher	*Tamerix chinensis*	TYPE 5
SC5S	Salt cedar, Type 5, sparse	*Tamerix chinensis*	TYPE 5
SC5t	Salt cedar, Type 5, treated	*Tamerix chinensis*	TYPE 5
SC6	Salt cedar, Type 6	*Tamerix chinensis*	TYPE 6U
SC6S	Salt cedar, Type 6, sparse	*Tamerix chinensis*	TYPE 6U
SC-C5	Salt cedar-Cottonwood, Type 5	*Tamerix chinensis-Populus fremontii var. wislizenii*	TYPE 5
SC-C6S	Salt cedar-Cottonwood, Type 6, sparse	*Tamerix chinensis-Populus fremontii var. wislizenii*	TYPE 6U
SC-CW5	Salt cedar-Coyote Willow, Type 5	*Tamerix chinensis-Salix exigua*	TYPE 5

H&O Code	Hink & Omart Description	Scientific Name (*Genus species*)	HSI Cover Type
SC-CW5pt	Salt cedar-Coyote Willow, Type 5, plant, treated	*Tamerix chinensis-Salix exigua*	TYPE 5
SC-RO/SC3	Salt cedar-Russian olive/Salt cedar, Type 3	*Tamerix chinensis-Elaeagnus angustifolia/Tamerix chinensis*	TYPE 3
SC-RO/SC-RO3	Salt cedar-Russian olive/Salt cedar-Russian olive, Type 3	*Tamerix chinensis-Elaeagnus angustifolia/Tamerix chinensis-Elaeagnus angustifolia*	TYPE 3
SC-RO/TW-SE3	Salt cedar/Russian olive-Tree Willow (Peach-leaf willow or Goodding willow)-Siberian elm, Type 3	*Tamerix chinensis-Elaeagnus angustifolia/Salix gooddingii-Ulmus pumila*	TYPE 3
SC-RO5	Salt cedar-Russian olive, Type 5	*Tamerix chinensis-Elaeagnus angustifolia*	TYPE 5
SC-SE5pt	Salt cedar-Siberian elm, Type 5, plant, treated	*Tamerix chinensis-Ulmus pumila*	TYPE 5
SE/MB-TH3	Siberian elm/Mulberry-Tree of Heaven, Type 3	*Ulmus pumila/Morus-Ailanthus altissima*	TYPE 3
SE/SC3	Siberian elm/Salt cedar, Type 3	*Ulmus pumila/Tamerix chinensis*	TYPE 3
SE1	Siberian elm, Type 1	*Ulmus pumila*	TYPE 1
SE5bt	Siberian elm, Type 5, burned, treated	*Ulmus pumila*	TYPE 5
SE-C/SC1	Siberian elm-Cottonwood/Salt cedar, Type 1	*Ulmus pumila-Populus fremontii var. wislizenii/Tamerix chinensis*	TYPE 1
SE-C1	Siberian elm-Cottonwood, Type 1	*Ulmus pumila-Populus fremontii var. wislizenii*	TYPE 1
SE-RO/SC-CW5	Siberian elm-Russian olive/Salt cedar-Coyote Willow, Type 5	*Ulmus pumila-Elaeagnus angustifolia/Tamerix chinensis-Salix exigua*	TYPE 5
SS6t	Sand sage, Type 6, treated	*Artemisia filifolia*	TYPE 6T
TW5Sbpt	Tree Willow (Peach-leaf willow Goodding willow), Type 5, sparse, burned, planted and treated		TYPE 5
TW-C4	Tree Willow (Peach-leaf willow Goodding willow)-Cottonwood, Type 4		TYPE 4U
TW-SE/CW3	Tree Willow (Peach-leaf willow Goodding willow)-Siberian elm/Coyote Willow, Type 3		TYPE 3
WM	Utility areas not considered “habitat”		UTILITY

Six general plant vegetation categories were developed by Hink and Ohmart (1984), based on the height of the vegetation and the make-up of the understory or lower layers:

- Forest Types I & III (untreated only)
- Forest Types II & IV (untreated and treated)
- Shrub Type V (untreated only)
- Dry Meadow Type VI (untreated and treated)
- Wet Meadow Type VI (untreated only)

Armed with this information, Table F2 offers a crosswalk between the H&O classification system and the cover type mapping performed for the HSI modeling efforts.

Table F3. List of undesirable indicator species when applying the model.

Life Form	Scientific Name	Common Name	Kartez Symbol	NHNM-ACRO1
Trees	*Ailanthus altissima*	tree of heaven	AIAL	AILALT
	Elaeagnus angustifolia	Russian olive	ELAN	ELAANG
	Ulmus pumila	Siberian elm	ULPU	ULMPUM
	Tamarix ramosissima	saltcedar	TARA	TAMRAM
Graminoids	*Agrostis gigantea*	redtop	AGGI2	AGRGIG
	Bromus catharticus	rescuegrass	BRCA6	BROCAT
	Bromus japonicus	Japanese brome	BRJA	BROJAP
	Bromus tectorum	cheatgrass	BRTE	BROTEC
	Cynodon dactylon	bermudagrass	CYDA	CYNDAC
	Hordeum murinum	mouse barley	HOMU	HORMUR
	Saccharum ravennae	ravennagrass	SARA3	SACRAV
	Sorghum halepense	johnsongrass	SOHA	SORHAL
Forbs	*Kochia scoparia*	common kochia	KOSC	KOCSCO
	Lepidium latifolium	perennial pepperweed	LELA2	LEPLAT
	Salsola tragus	prickly Russian thistle	SATR12	SALTRA
	Aster spp.	dandelion		
	Solidago spp.	Solidago		
	Salsola kalii	tumbleweed	SAKA	SALKAL
	Cardaria draba (L.) Desv.	Hoary cress		
	Alhagi pseudalhagi (Bieb) Desv.	camelthorn		
	Euphorbia esula L.	leafy spurge		
	Peganum harmala L.	African rue		
	Centaurea maculosa Lam.	spotted knapweed		
	Centaurea solstitialis L.	yellow starthistle		
	Carduus natuans L.	musk thistle		

Table F4. List of native indicator species when applying the model.

Life Form	Scientific Name	Common Name	Kartez Symbol	NHNM-ACRO1
Trees	*Populus deltoides ssp. wislizeni*	Rio Grande cottonwood	PODEW	POPDELW
	Salix gooddingii	Goodding's willow	SAGO	SALGOO
Shrubs	*Amorpha fruticosa*	desert indigobush	AMFR	AMOFRU
	Forestiera pubescens	New Mexico olive	FOPU2	FORPUB
	Salix exigua	coyote willow	SAEX	SALEXI
	Baccharis spp	baccharis		
	Ribes aureum	golden currant		
	Rhus sp	sumac		
	Lycium torii	wolfberry		
	Shepherdia argentea	silver buffalo berry		
Graminoids	*Carex spp.*	sedge	CAREX	CAREX
	Cyperus spp.	flatsedge	CYPER	CYPERU
	Juncus spp.	Rush	JUNCU	JUNCUS
	Muhlenbergia asperifolia	alkali muhly	MUAS	MUHASP
	Oryzopsis hymenoides	Indian ricegrass	ORHY	ORYHYM
	Panicum spp.	panicgrass	PANIC	PANICU
	Sorghastrum nutans	Indiangrass	SONU2	SORNUT
Forbs	*Anemopsis californica*	yerba mansa	ANCA10	ANECAL

Undesirable vs. desirable species lists

In addition, the E-Team developed a list of “indicator” species to serve as proxies to capture the desired vegetative composition and diversity in a restored bosque ecosystem. Table F3 is a list of the undesirable “indicator” species and Table F4 lists the native species of concern for Bosque Riparian HSI model applications (variable codes include INDICATFB, INDICATGR, INDICATHB, SPPCOUNT, NATIVETREE, and NATIVESDG).

Field sampling protocols and diagrams

Three specific protocols were used to measure the vegetative conditions on the references sites for the MRGBER study: 1) point-intercept, 2) line-intercept, and 3) point-centered quarter. Each of these methodologies is illustrated below, in the hope that these techniques can be repeated by future users for various reasons (i.e., to perform validation of the model; facilitate a monitoring program using the HSI model; apply the model elsewhere, etc.).

Point-Intercept technique

The point-intercept[1] technique was used to measure the numerous herbaceous canopy cover parameters (CANFORB, CANGRASS, CANHERB, CANSEDGE), and was calculated by dividing the number of “hits” on a plant by the total number of sample points taken along the transect. Narrow points (e.g. a nail on the bottom of a wooden dowel) were vertically lowered through a frame (e.g. a camera tripod) at pre-determined intervals along the transects (in this case, every 2 m). As the pin moved towards the ground, every plant that made contact with the pin was recorded as a “canopy hit” (as opposed to a “basal hit,” described below in the ground cover section above). A canopy “hit” included any pin contact with a plant leaf, stem, or flower (Figure F1).

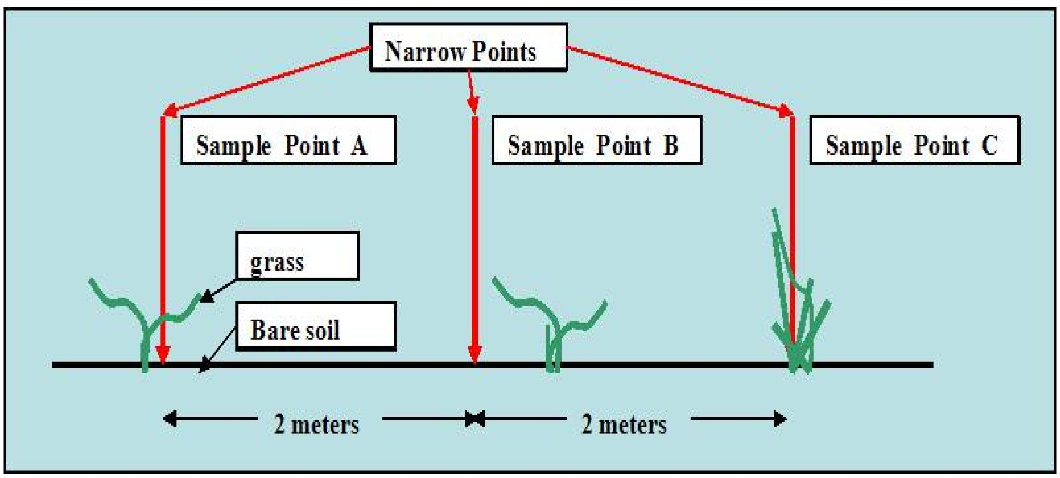


Figure F1. Illustration of the point-intercept method used to record aerial herbaceous plant cover for the MRGBER study.

In the example, the observer would record “grass” as a canopy “hit” and “soil” as a ground cover “hit” (*COVGRND* and *CTGRNDCOV)* at **Sample Point A**. For **Sample Point B**, there would be no aerial “hit” recorded, but the ground cover “hit” would be recorded as “litter.” For **Sample Point C**, both the aerial and the ground cover “hits” would be recorded as “grass.” To increase efficiency and considering the project goals, the field team only recorded canopy hits according to plant life-form (i.e., grass, forb, sedge, or rush). The only exception to this rule was if the pin made contact with a highly desirable or undesirable plant species (“indicator species”) (i.e.,

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1 While all methods for estimating plant cover have their advantages and disadvantages, points were considered the most objective way to estimate plant cover (Bonham 1989) and for herbaceous plants, is considered more precise and efficient than estimating aerial cover with quadrats (Bonham 1989; Chambers and Brown 1983; Elzinga et. al. 1998; Floyd and Anderson 1987).

INDICATFB, *INDICATGR*, *INDICATHB*, and *NATIVESDG*). In those instances, it was mandatory for the species to be identified along with the "hit."

Line-Intercept

The line-intercept method proved to be a fast and efficient way to estimate shrub canopy cover (*CANSHRUB*) over large areas of the study. The line-intercept method was run using the existing cross transects. Any shrub crowns that overlapped or intercepted the transect line were recorded (by species) (Figure F2).

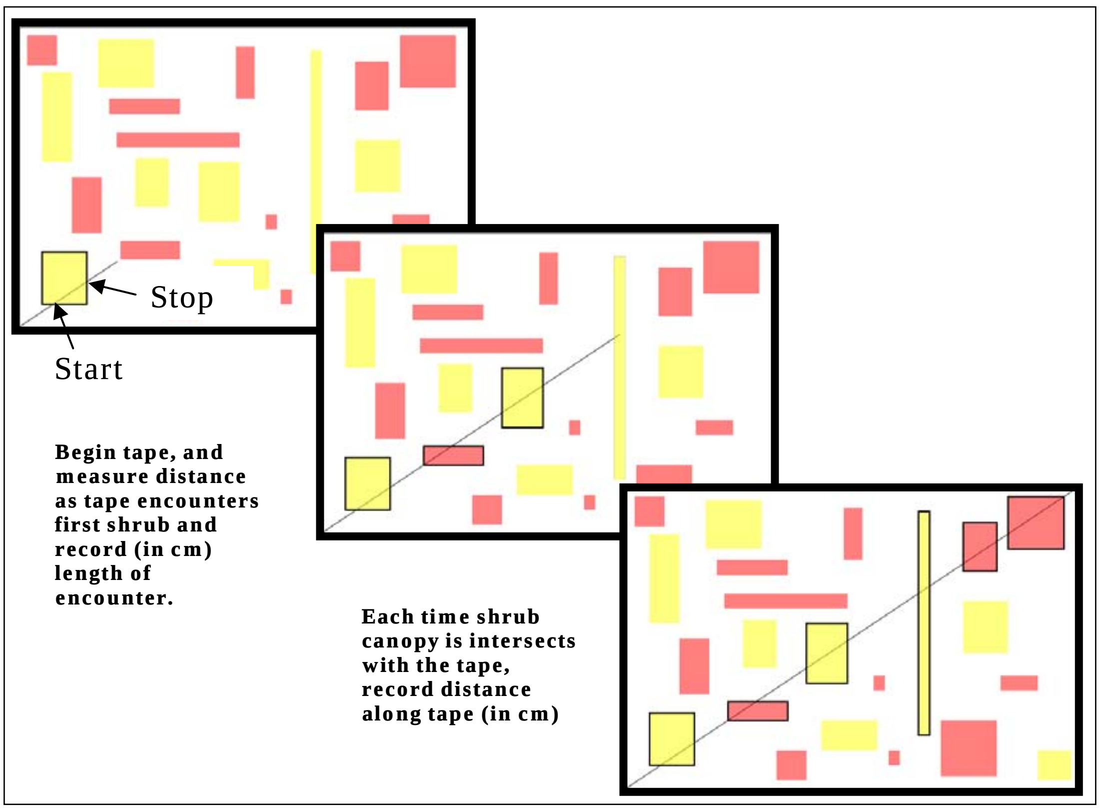

Figure F2. Illustration of the line-intercept method used to record shrub cover for the MRGBER study.

The beginning and end of where the canopy overhung the tape was recorded and later converted to percent cover. A pole with a level/optical sighting device was used, when necessary, to reduce observer bias when determining if a shrub was "in," and when determining the starting and ending points along the tape.[1]

[1] Information taken from http://ag.arizona.edu/AREC/pubs/rmg/1%20rangelandmanagement/5%20monitorrangebrowseveg93.pdf (September 2008) and diagram taken from http://en.wikipedia.org/

Point-centered quarter

The point-centered quarter method was known to be a frequently used distance method to sample forest communities (Bonham 1989; Cottam and Curtis 1956; Elzinga et al. 1998; Krebs 1999). After a sampling point along a transect was located (in this case, at the end of each cross arm), the area around those points was split into four 90° quadrants (quarters) and the distance to the nearest tree and root-sprout in each quarter was estimated with an optical rangefinder (*DISTBIGTR*) (Figure F3).

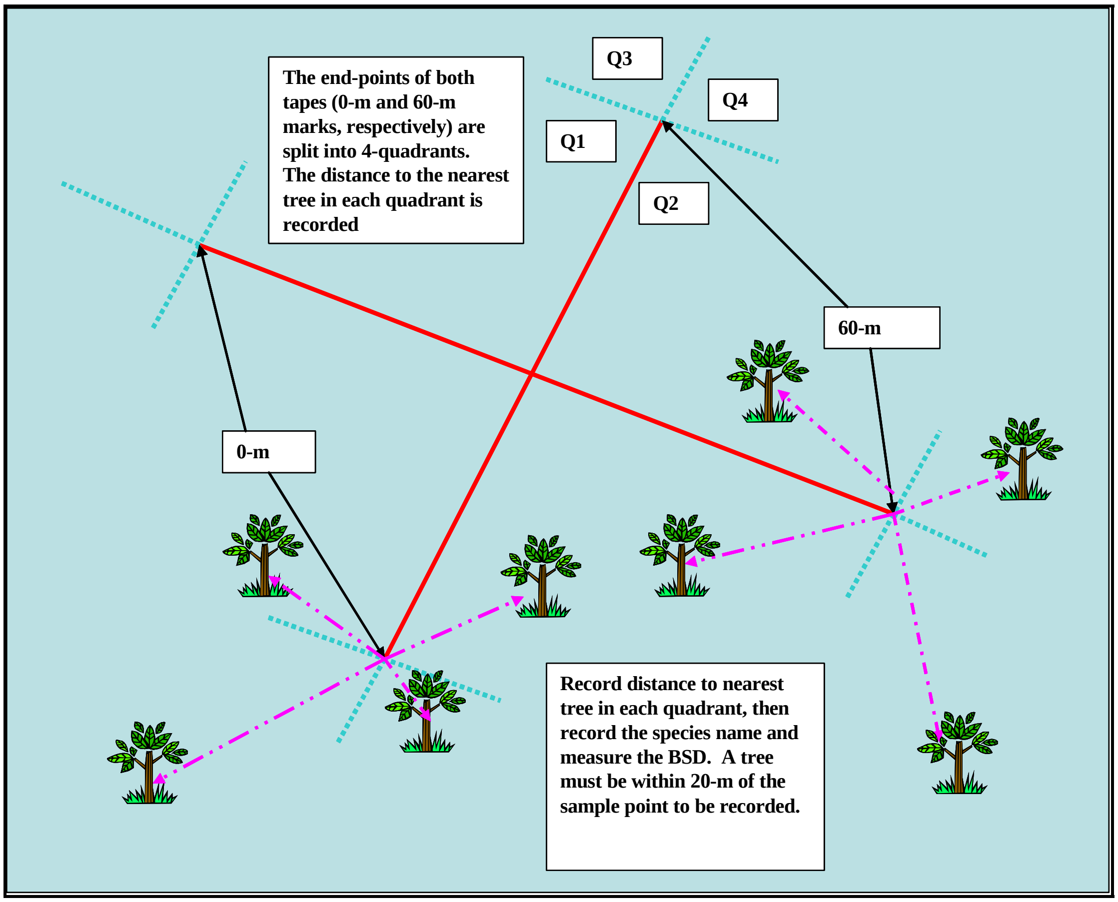

Figure F3. Illustration of point-centered quarter method used to record tree and root-sprout density and size.

The tree species was recorded and basal stem diameter of trees (not root-sprouts) was measured with calipers or a dbh tape and recorded on the data

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wiki/Image:LiTrSa42008Geelhoed.svg (September 2008).

sheet as well. Double counting was not allowed. To avoid the potential problem of double counting, the measurements were only recorded at the terminus of each cross arm, and a maximum distance of 20 m was applied for recording a tree in any PCQ quadrant. Krebs (1999) stressed the importance of accurately dividing each sampling point into four even quadrants. A compass with an optical rangefinder was used while standing at the sample point to ensure that a tree or root-sprout was actually in the quadrant of interest before recording it on the data sheet. In those instances where no tree within 20 m in a particular quadrant was found, the team recorded a ">20-m" value on the data sheet. Equations for calculating density and basal area using PCQ are described in Krebs (1999).

Appendix G: Model Review Forms and Comments

Technical experts within and outside the facility (but still within the USACE planning community) reviewed both the model development process and the model itself. To assure fair and impartial review of the products, members of the Laboratory-based Technical Review Team (LTRT) were chosen on the basis of expertise, seniority in the laboratory chain of command, and USACE planning experience.

The following were members of the LTRT:

1. Dr. Andrew Casper (ERDC-EL) – technical (peer) reviewer
2. Ms. Kristine Nemec (Kansas City District) – technical (peer) reviewer
3. Janean Shirley – editorial review (Technical Editor)
4. Ms. Antisa Webb - management review (Branch Chief)
5. Dr. Edmond J. Russo – management review (Division Chief)
6. Dr. Steve Ashby – program review (System-wide Water Resources Research Program, Program Manager)
7. Dr. Al Cofrancesco – program review (Technical Director)
8. Dr. Mike Passmore – executive office review (Environmental Laboratory Deputy Director)

No peer review members of the LTRT were directly associated with the development or application of the model(s) for this study, thus assuring <u>independent</u> technical peer review.[1] Referred to as the in-house Laboratory-based Technical Review (LTR), these experts were asked to consider the following issues when reviewing this document:

1. Whether the concepts, assumptions, features, methods, analyses, and details were appropriate and fully coordinated;
2. Whether the analytic methods used were environmentally sound, appropriate, reasonable; fall within policy guidelines; and yield reliable results;

1 Resumes for Dr. Casper and Ms. Nemec (i.e., the technical peer reviewers) can be found immediately following the comment/response tables at the end of this appendix.

3. Whether any deviations from USACE policy and guidance were identified, documented, and approved;
4. Whether the products met the Environmental Laboratory's standards based on format and presentation; and
5. Whether the products met the customer's needs and expectations.

Review comments and responses

Review comments were submitted to the Laboratory-based Project Delivery Team (LPDT) in written format and the LPDT responded in kind (Table G1). In the EL Electronic Manuscript Review System (ELEMRS) 2.0, both reviewers indicated that the document was "Acceptable" with grammatical/formatting modifications needed, and when asked to offer their opinion as to the production of the report, they stated that it was a "quality study, well designed and presented [with] important new information."

Table G1. Review comments.

Review Comments				
Project:	A Bosque Riparian Community Index Model for the Middle Rio Grande, Albuquerque, New Mexico		**Review Focus:** Model Documentation – Completeness, Scientific Basis (Editorial comments accepted as well)	
Reviewer	**Page/ Para**	**Chapter**	**Reviewer Comments**	**Response**
Kristine Nemec	Pg. 76 Table 4	4	(Wagner 2004), Jacob, Moulton and Lopez 2004) missing reference	Concur and rectified.
	Pg. 80 Table 4	4	Stamps 1991 missing reference	Concur and rectified.
	Pg. 104	Table 10	Explain why some cells are shaded black	Concur and explanation incorporated into table footnote.
		References	Missing or references included that were not cited in text.	Concur and rectified.
	Throughout doc	NA	Grammar and spelling suggestions made in track changes format	Concur and incorporated.
	Pg. 6	1	The Middle Rio Grande study documentation identified and recommended effective, affordable and environmentally sensitive ecosystem restoration features throughout the middle reach of the Rio Grande system. Should you add the 905(b) or quote the problem statement?	Do not concur – the reader must turn to the feasibility documentation to investigate study goals and objectives. The purpose of this report is to document the model – not its use.
	Pg. 7 Para 1		Do you think a definition of function is necessary?	Concur – a definition of function has been incorporated into the text and added to the glossary.

Review Comments

Project: A Bosque Riparian Community Index Model for the Middle Rio Grande, Albuquerque, New Mexico

Review Focus: Model Documentation – Completeness, Scientific Basis (Editorial comments accepted as well)

Reviewer	Page/ Para	Chapter	Reviewer Comments	Response
	Pg. 7 Para 2		Baseline - Should you use planner speak - inventory or FWOP?	Do not concur – the syntax in the model documentation follows standard USACE planning paradigm. As such, baseline is not the future without-project condition, nor is it wholly equal to the term inventory. An inventory can include more than the baseline condition per the model. The Without project-condition describes changes into the future from the baseline condition under a "No Action" scenario.
Kristine Nemec	Pg. 8 Para 2		In May of 2005, the PMIP developed Engineering Circular (EC) 1105-2-407, Planning Models Improvement Program: Model Certification (USACE 2005).	No – documents cited in this section are current.
	Pg. 9 Para 4	1	Developed - And certified? Or state that certification is not needed	The HEAT software has been recommended for certification, but has not been certified as of December 2009. ERDC-EL is incorporating reviewer changes to the User Guide, and will be submitting the software for certification to USACE-Headquarters soon.
	Pg. 15 # 5	2	Conduct field sampling - Can it also be done with pre-existing GIS files?	Although it could be done with pre-existing GIS data to some extent, it was not handled in this manner, and any change from this protocol would necessitate an external peer review (i.e., review via model certification protocols). As such, this issue was not addressed in the document.
	Pg. 21 Figure 1	3	Figure 1 I can't tell what the right figure # is this should be 5? (the next is Figure 6)	Concur and rectified.
	Pg. 23 Para 1	3	Subsequent iterative refinement of these models led to the identification of contributing ecosystem components, and a description of associated variables (with suggested sampling protocols) that can be used to measure ecosystem restoration benefits. Citation? Is his sentence needed?	Do not concur – this sentence if absolutely necessary, and original. Therefore no citations are necessary.
Andy Casper	Pg. 28 Para 1 (heading)	3	Climatic Characterization - Citations? Maybe 'Dahm, C.M., Edwards, R.J. and F.P. Gelwick. 2005. The Gulf Coast Rivers of the South-western United States. Chapter 5. In: The Rivers of North America . Benke, A.C. and C. E. Cushing (eds.). Academic Press, Inc.	Do not concur - Citations unnecessary as this information was taken from the internet and weather citations provided therein.
	Pg. 37 Para 2	3	It should be noted, - It is unclear what the significance is? Does this add/subtract one of the categories? Affect them some other way?	Do not concur – significance is provided at the end of the paragraph.

Review Comments				
Project: A Bosque Riparian Community Index Model for the Middle Rio Grande, Albuquerque, New Mexico			Review Focus: Model Documentation – Completeness, Scientific Basis (Editorial comments accepted as well)	
Reviewer	Page/ Para	Chapter	Reviewer Comments	Response
	Pg. 39 Para 1	3	Clearing activities have greatly reduced the acreage of Type I, III, and V woodlands. Recently-created Type II stands are largely devoid of understory vegetation - Significance to the model is not clear.	Do not concur – significance is provided at the end of the paragraph.
Andy Casper	Pg. 39 & 40 Last & first para	3	Because the "treated" habitats were significantly different in terms of vegetative cover, infiltration, etc., from the "untreated" cover types in the region, the E-Team made a decision to capture these differences by dividing several of the Hink and Ohmart categories (namely Types II, IV, and VI) into "Treated" and "Untreated" classifications (designated by "U's") to better capture the degraded habitat conditions in "fire managed" areas within the study boundary . . . " – Ah here it is! Maybe add an intro sentence to the first paragraph in this section that says something like 'The prevalence of fire in the riparian community can have a strong impact on the six categories.' So the reader knows why they are reading about fire in a water project.	Do not concur – significance is provided at the end of the paragraph.
	Pg. 40 Para 2	3	Open areas not associated with the model have been mapped, and offer potential areas of restoration and rehabilitation within the study area. I am confused , if it is not part of the accounting the model, it is per force not part of the restoration – why even bring it up if it doesn't affect the project somehow.	Do not concur - Although this is an application question, the point of this statement is that unassociated habitats CANNOT be assessed with the model, and yet a full accounting of landuse/landcover classifications must be completed in order to balance the books. Unassociated habitat <u>can be</u> enhanced/restored in such a manner that the conversion allows for model assessment.
	Pg. 87 Table 5	4	Need protocol from Ondrea	Concur and rectified.

Reviewer Curriculum Vitae

US Army Corps of Engineers

U.S. ARMY

ERDC

Professional Experience

Dr. Andrew F. Casper

Research Biologist - ERDC, Environmental Laboratory
3909 Halls Ferry Rd., Vicksburg, MS 39180
601-634-4681
Andrew.F.Casper@usace.army.mil

Research Biologist, Aquatic Ecology and Invasive Species Branch, Engineer Research and Development Center, Environmental Laboratory, Vicksburg, MS., 2006 to present.

- Specializing in large river science, engineering and ecology spanning the continent from Gulf Coast rivers and estuaries to the Ohio and Mississippi River Valley's to the arctic Mackenzie River Delta and Beaufort Sea in Canada
- Development of conceptual, physical habitat, and watershed models
- Modeling climate change and land use impacts/responses
- Assessment of dam removal and ecological restoration
- Food web and community ecology techniques for fish and invertebrates in large navigable rivers and flood plains
- GIS-based, 2-D water quality mapping in tidal creeks/coastal rivers

Education

- **Ph.D.** Océanography, 2005,
  Université Laval, Québec City, QC.
- **M.S.** Biological Sciences,1993
  Southern Illinois University Carbondale.
- **B.S.** Natural Sciences, 1990
  Southern Illinois University Carbondale

Research & Teaching

- A.F. Casper and C. Fischenich. Framework and Integration of Conceptual Models in the CoE Planning Process (System Wide Water Resource Program Environmental Benefits Analysis Program, USACE HQ).
- Brasfield, S., A.F. Casper and B. S. Payne. Potential Contribution of Climate Change to the Bioassessment of Contaminants on Military Installations: Additive, Synergistic or Antagonistic? (USACE ERDC Basic Research Program).
- K. J. Killgore, J. J. Hoover, D. R. Johnson, and A. F. Casper. Envirofish: A HEC compatible floodplain habitat model for evaluating mitigation scenarios (reimbursable project for D. R. Johnson, Mississippi Valley District).

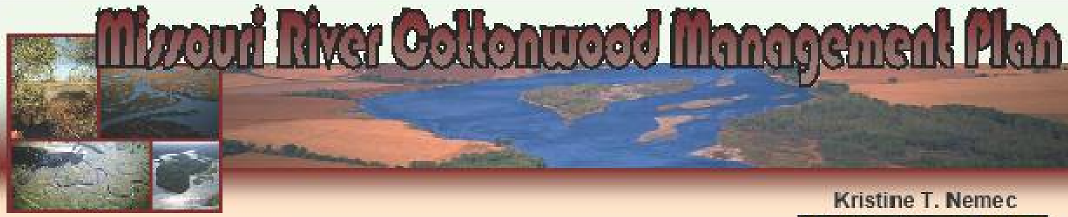
Other Professional Activities

- Ecosystem restoration/mitigation
- Sensitivity analysis and incorporation of risk/ uncertainty
- Forecasting effects of scenarios and plan formulations
- Project/Watershed cumulative impacts assessments
- Coordinate field collections, management, analysis and reporting for river ecology
- SOW proposal and budget writing for multi-year research projects (NSF, EPA, USACE)

Selected Publications & Conference Presentations

- Casper, R. A. Efoymson, S. M. Davis, G. Steyer, and B. Zettle. 2009. Improving Conceptual Model Development: Avoiding Underperformance Due to Project. U.S. Army Engineer Reseawrch and Development Center, Vicksburg, MS.
- Casper A. F., and J. H. Thorp. 2007. Diel and lateral patterns of zooplankton distribution in the St. Lawrence River. Rivers Research and Application 23(1):73-85.
- Casper, A. F., J. H. Thorp, S. P. Davies, and D. L. Courtemanch. 2006. Ecological responses of large river benthos to the removal of the Edwards Dam on Kennebec River, Maine (USA). Archiv fur Hydrobiologie 16(4):541-555 (Large River Supplement 115).
- June 2008 – A surrogate model for future regional climate change: The current affects of the Atlantic Multidecadal Oscillation and its influence on the ecohydrology of Great Lakes and New England rivers. 56th Annual North American Benthological Society International Conference, Salt Lake City, Utah.
- July 2007 - Linking ecological responses to hydrologic characteristics of rivers: Examples from studies of dam removals and PHABSIM modeling for minimum flow standards. US Army Corps of Engineers Waterways Experiment Station. Vicksburg MS.
- A. F. Casper, B. Dixon, E. Steimle, J. Gore, P. Coble, and R. Conmy. Water quality sampling strategies for monitoring coastal rivers & estuaries: Applying technological innovations to Tampa Bay tributaries. Awarded by USEPA (Oct 2006 - Dec 2007).
- Carrabetta, M., A. F. Casper, B. Chernoff, and M. Daniels. The ecological and physical effects of removal of two low-head dams on Eight Mile Creek, a tributary of the Connecticut River. Awarded by TNC/NOAA Community Restoration Program (2005-07).

September 2009



Kristine T. Nemec

USACE - Omaha District
1616 Capitol Avenue
Omaha, NE 68102
402-995-2685
Kristine.t.nemec@usace.army.mil

Professional Experience

Environmental Resources Specialist, U.S. Army Corps of Engineers, Omaha District, December 2002 to present

- Prepare environmental assessments required under the National Environmental Policy Act for shallow water habitat and emergent sandbar habitat projects along the Missouri River
- Designed planting specifications for riparian forest restorations in South Sioux City, Nebraska; Sioux Falls, South Dakota; and Lower Brule Sioux Reservation, South Dakota
- Served on the South Dakota Bald Eagle Management Team, 2003-05
- Developed environmental sections of mater plan updates for Gavins Point and Oahe projects in South Dakota

Education

- **Ph.D.,** In progress
  University of Nebraska at Lincoln, Lincoln, NE
- **M.S.,** Biology, 2003
  University of Nebraska at Omaha, Omaha, NE
- **B.S.,** Environmental Studies, 1999
  University of Nebraska at Omaha, Omaha, NE
  Summa Cum Laude. University Honors Program

Research & Teaching

- Restoration ecology, agroecology, and ecological resilience
- Conducted fieldwork during the summer for research projects in forest, wetland, and grassland ecosystems in Nebraska, 1995 to present
- Taught undergraduate and graduate students in Ecology, Biology I, and Biology II labs at the University of Nebraska at Omaha

Awards/Honors

- J. E. Weaver Competitive Grant. The Nature Conservancy, 2009
- Center for Great Plains Studies Grant. Center for Great Plains Studies, 2008
- Contributed two articles to a newspaper series on Platte River water issues which received the Nebraska Wildlife Federation's Conservation Communicator award, 2006 and the Renewable Natural Resources Foundation's national Excellence in Journalism award, 2007

Selected Publications & Conference Presentations

Nemec, K. T., C. R. Allen, A. Alai, G. Clements, A. Kessler, T. Kinsell, A. Major, and B. J. Stephen. Woody invasions of urban parks and trails and the changing face of urban forests in the Great Plains, USA. (Submitted for publication, Biological Invasions).

Invited speaker for cottonwood panel discussion sponsored by the Izaak Walton League, Sioux City, Iowa, 2008.

Presented poster entitled "Lower Brule Shoreline Protection and Cottonwood Habitat Enhancement Project, Lake Sharpe, South Dakota" at the Second National Conference on Ecosystem Restoration, Kansas City, Missouri. 2007.

Delivered presentation entitled "Cottonwood Community Delineation" at the Corps of Engineers Wildlife Workshop, Omaha, Nebraska. 2006.

Presented poster entitled "Cottonwood Management and Regeneration along the Missouri River" at the First National Conference on Ecosystem Restoration, Orlando, Florida. 2004.

Other Professional Activities

- Society for Ecological Restoration
- Ecological Society of America
- Nebraska Native Plant Society
- Association for Women in Science

September 2009

Administrative review status and technical transfer forms

The documentation is now in senior staff and program management review. Two technology transfer forms will be completed when the document has been reviewed and approved by both the senior staff and the program managers (Tables G2 and G3).

Table G2. Internal ERDC-EL Technology Transfer Review Form.

TECHNOLOGY TRANSFER STATUS SHEET	
INSTRUCTIONS The author(s) of a document based on ERDC-EL research and written for publication or presentation should attach one copy of this sheet to the document when the first draft is prepared. Documents include reports, abstracts, journal articles, and selected proposals and progress reports. The sheet will remain with the most recent draft of the document.	
JOB NUMBERS: a. **WORD PROCESSING SECTION** ____ b. ENVIRONMENTAL INFORMATION ANALYSIS CENTER _________________________________ c. **VISUAL PRODUCTION CENTER** ____	
2. TITLE	3. AUTHOR(S)
4. PRESENTATION (Conference Name & Date)	5. PUBLICATION (TR, IR, MP, Journal Name, etc.)
6. SPONSOR OR PROGRAM WORK UNIT	7. DATE REQUIRED BY SPONSOR
8. DATE DRAFT COMPLETED BY AUTHOR(S) AND AREADY FOR SECURITY OR TECHNICAL REVIEW	
9. SECURITY REVIEW (Military Projects) a. THIS DOCUMENT HAS BEEN REVIEWED FOR SECURITY CLASSIFICATION FOLLOWING GUIDELINES SPECIFIED IN AR 380-5, DEPARTMENT OF THE ARMY INFORMAITON SECURITY PROGRAM, AND FOUND TO BE: CLASSIFIED __________ CONFIDENTIAL ______ SECRET _________ TOP SECRET _____ UNCLASSIFIED _______ SENSITIVE __________ DISTRIBUTION LIMITED ______________ CLASSIFICATION WAS BASED ON THE ____ SECURITY CLASSIFICATION GUIDE DATED ____________________________________	
10. AUTHOR	11. DATE
12. GROUP/DIVISION CHIEF	13. DATE
14. IN-HOUSE TECHNICAL REVIEW (To be completed by two or more reviewers who are GS-12 or Above, Expert, or Contractor) a. __________________ ____________________ _______________ __________________ DATE TO REVIEWER DATE RETURN REQUESTED DATE RETURNED TECHNICAL REVIEWER ____ ACCEPTABLE W/MINOR REVISIONS ____ ACCEPTABLE W/MAJOR REVISIONS ____ UNACCEPTABLE b. __________________ ____________________ _______________ __________________ DATE TO REVIEWER DATE RETURN REQUESTED DATE RETURNED TECHNICAL REVIEWER ____ ACCEPTABLE W/MINOR REVISIONS ____ ACCEPTABLE W/MAJOR REVISIONS ____ UNACCEPTABLE c. __________________ ____________________ _______________ __________________ DATE TO REVIEWER DATE RETURN REQUESTED DATE RETURNED TECHNICAL REVIEWER ____ ACCEPTABLE W/MINOR REVISIONS ____ ACCEPTABLE W/MAJOR REVISIONS ____ UNACCEPTABLE NOTE: RETURN TO AUTHOR WHEN TECHNICAL REVIEW IS COMPELTED.	

ERDC FORM 2378
R OCT 89 PREVIOUS EDITIONS ARE OBSOLETE. (CONTINUED ON REVERSE)

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DATE TO GROUP CHIEF DATE RETURN REQUESTED DATE RETURNED GROUP CHIEF

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16. PROGRAM MANAGER REVIEW (If Appropriate)

_________________________ _______________________ _________________ ____________________
DATE TO PROGRAM MANAGER DATE RETURN REQUESTED DATE RETURNED PROGRAM MANAGER

17. COMPLETE THE FOLLOWING FOR ALL REPORTS

a. RECOMMEND TYPE OF REPORTS (TR, IR, MP, Or Other):

____

b. LEVEL OF EDITING (Type 1, 2, 3, Or 4):

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c. IF TYPE 1 OR 2 EDITING IS INDICATED, ADD A BRIEF JUSTIFICATION:

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SIGNATURE OF DIVISION CHIEF

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Reverse of ERDC Form 2378, R OCT 89

Table G3. Security Clearance Form for ERDC-EL reports.

REQUEST FOR CLEARANCE OF MATERIAL CONCERNING CIVIL WORKS FUNCTIONS OF THE CORPS (ER 360-1-1)		
THRU	TO CDR, USACE CEPA-ZM WASH, DC 20314-1000	FROM

1. TITLE OF PAPER	
2. AUTHOR (NAME)	3. OFFICIAL TITLE AND/OR MILITARY RANK

4. THIS PAPER IS SBUMITTED FOR CLEARANCE PRIOR TO PRESENTATION OR PUBLICATION AS IT FALLS INTO THE CATEGORY (OR CATEGORIES) CHECKED BELOW:	
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6. FOR PRESENTATION TO: ORGANIZATION: CITY AND STATE:	
7. DATE OF FUNCTION	8. DATE CLEARED PAPER IS REQUIRED
9. FOR PUBLICATION (Name of Publication Media)	10. DATE CLEARED PAPER IS REQUIRED

THIS PAPER CONTAINS NO CLASSIFIED ORIGINAL OR DERIVATIVE MATERIAL.		
DATE	NAME AND TITLE (Approving Authority)	SIGANTURE (Approving Authority)

THRU	TO	FROM CDR, USACE CEPA-ZM WASH, DC 20314-1000
1. SUBJECT MANUSCRIPT IS CLEARED FOR PRESENTATION AND PUBLICATION:		
☐ WITHOUT CHANGE	☐ WITH CHANGES ANNOTATED ON THE MANUSCRIPT	☐ WITH SUGGESTED CHANGES AND/OR COMMENTS ATTACHED
2. RETURNED WITHOUT CLEARANCE FOR THE FOLLOWING REASON(S):		
DATE	NAME AND TITLE (Approving Authority)	SIGNATURE (Approving Authority)

ENG FORM 4329-R, APR 91 | EDITION OF JAN 82 IS OBSOLETE. | (Proponent; CEPA-I)

INSTRUCTIONS FOR SUBMISSION OF MATERIAL FOR CLEARANCE (ENG Form 4239-R)

1. An original and two copies of papers or material on civil works functions or other non-military matters requiring HQUSACE approval, will be forwarded to reach HQUSACE at least 15 days before clearance is required. Including any maps, pictures and drawings, etc., referred to in the text.

2. Technical papers containing unpublished data and information obtained by the author in connection with his/her official duties will contain the following acknowledgement when released for publication outside the US Army Corps of Engineers. The acknowledgement will identify the research program which provided resources for the paper, the agency directing the program and a statement that publication is by permission of the Chief of Engineers.

The tests described and the resulting data presented herein, unless otherwise noted, were obtained from research conducted under the _______________ of (Program) the United States Army Corps of Engineers by the ___________________. Permission was granted by (Agency) the Chief of Engineers to publish this information.

3. When manuscripts are submitted for publication in THE MILITARY ENGINEER, a brief biographical sketch (100 to 150 words) of the author is required, indicating his/her background in the subject matter.

Certificate of Product Check

This certifies that adequate review was provided by all appropriate disciplines to verify the following:

1. Correct application of methods;
2. Adequacy of basic data and assumptions;
3. Completeness of documentation;
4. Compliance with guidance, standards, regulations, and laws; and
5. Correct study approach.

____

Kelly A. Burks-Copes Date
Principal Investigator
Environmental Laboratory
U.S. Army Engineer Research and Development Center
Vicksburg, MS

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE ***(DD-MM-YYYY)***	**2. REPORT TYPE**	**3. DATES COVERED** ***(From - To)***
September 2012	Final report	

4. TITLE AND SUBTITLE

A Bosque Riparian Community Index Model for the Middle Rio Grande, Albuquerque, New Mexico: Model Documentation

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Kelly A. Burks-Copes and Antisa C. Webb

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Environmental Laboratory
U.S. Army Engineer Research and Development Center
3909 Halls Ferry Road
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8. PERFORMING ORGANIZATION REPORT NUMBER

ERDC/EL TR-12-26

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U.S. Army Corps of Engineers
Washington, DC 20314-1000

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Over the last century, the Middle Rio Grande was subjected to significant anthropogenic pressures producing a highly degraded ecosystem that today is poised on the brink of collapse. In 2002, the U.S. Army Corps of Engineers (USACE) (Albuquerque District) was authorized to study the river and prepare an Environmental Assessment (EA), as required under the tenets of the National Environmental Policy Act (NEPA), to evaluate the effects of proposed ecosystem restoration alternatives on the watershed's significant resources. As part of the process, a multi-agency, multi-disciplinary evaluation team was established to formulate alternatives that would address three critical problems: 1) hydrological alterations, 2) bosque (riparian) ecosystem degradation, and 3) the loss of key ecological services to the surrounding community. Between 2005 and 2008, this team designed, calibrated, and applied a community-based index model for the bosque riparian ecosystem using field and spatial data gathered from 27 reference sample sites scattered across the watershed. This unique community was modeled using 23 individual variables combined into numerous predictive community functional components (i.e., Biotic Integrity, Hydrology, and Spatial context) capable of capturing the changes to ecosystem integrity in response to changes in land and water management activities proposed by the study. The intent of this document is to provide the scientific basis upon which the model was developed, and describe the 3-year-long process the team undertook to complete this effort. Although some results are presented here to demonstrate and verify the veracity of the model's calibration and subsequent outputs, readers interested in the application of this model on the Middle Rio Grande project must refer to a second report entitled, "Middle Rio Grande Bosque Ecosystem Restoration Feasibility Study Habitat Assessment Using Habitat Evaluation Procedures (HEP): Analyses, Results and Documentation," which is currently in preparation.

15. SUBJECT TERMS

Albuquerque District	Ecosystem restoration	National Environmental Policy Act (NEPA)
Bosque Riparian	Environmental assessment	
	Middle Rio Grande River	

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	18. NUMBER OF PAGES	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER *(include area code)*
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED		172	